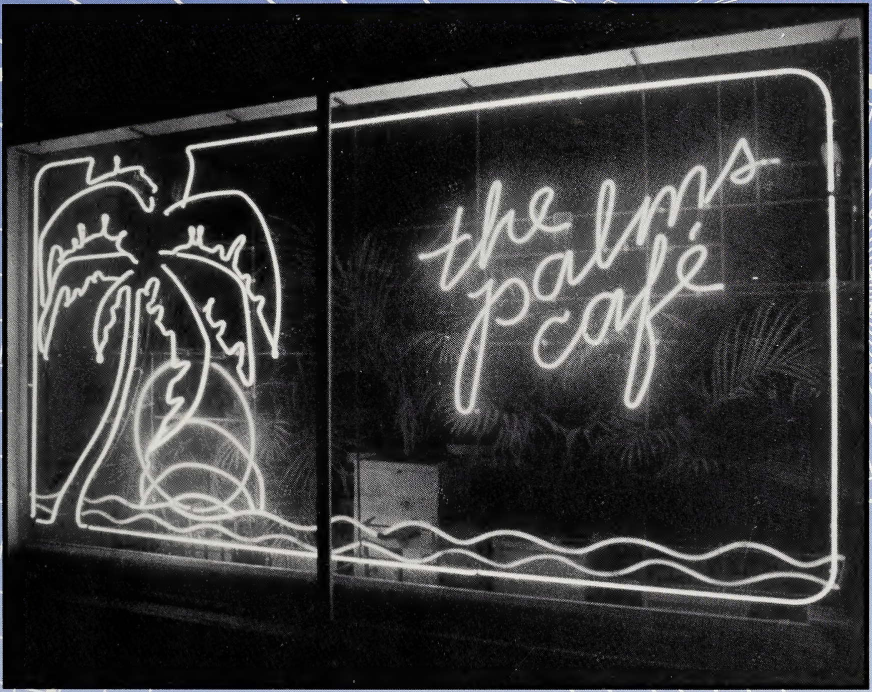
PHYSICS 30



Module 9

Models of the Atom

Distance Learning

Alberta EDUCATION

Physics 30

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Models of the Atom

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Distance Learning

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Physics 30
Student Module
Module 9
Models of the Atom
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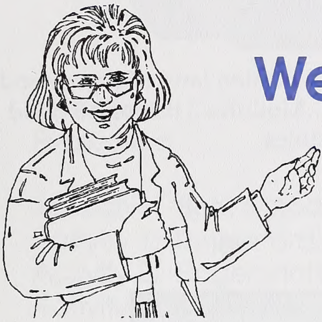
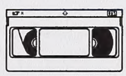


Welcome to Module 9!

We hope you'll enjoy your study of *Models of the Atom*.

To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.



You also have the option of viewing laser videodisc clips when you see the bar codes like this one.

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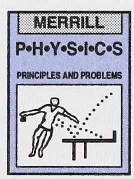
When you see this icon, study the appropriate pages in your textbook.



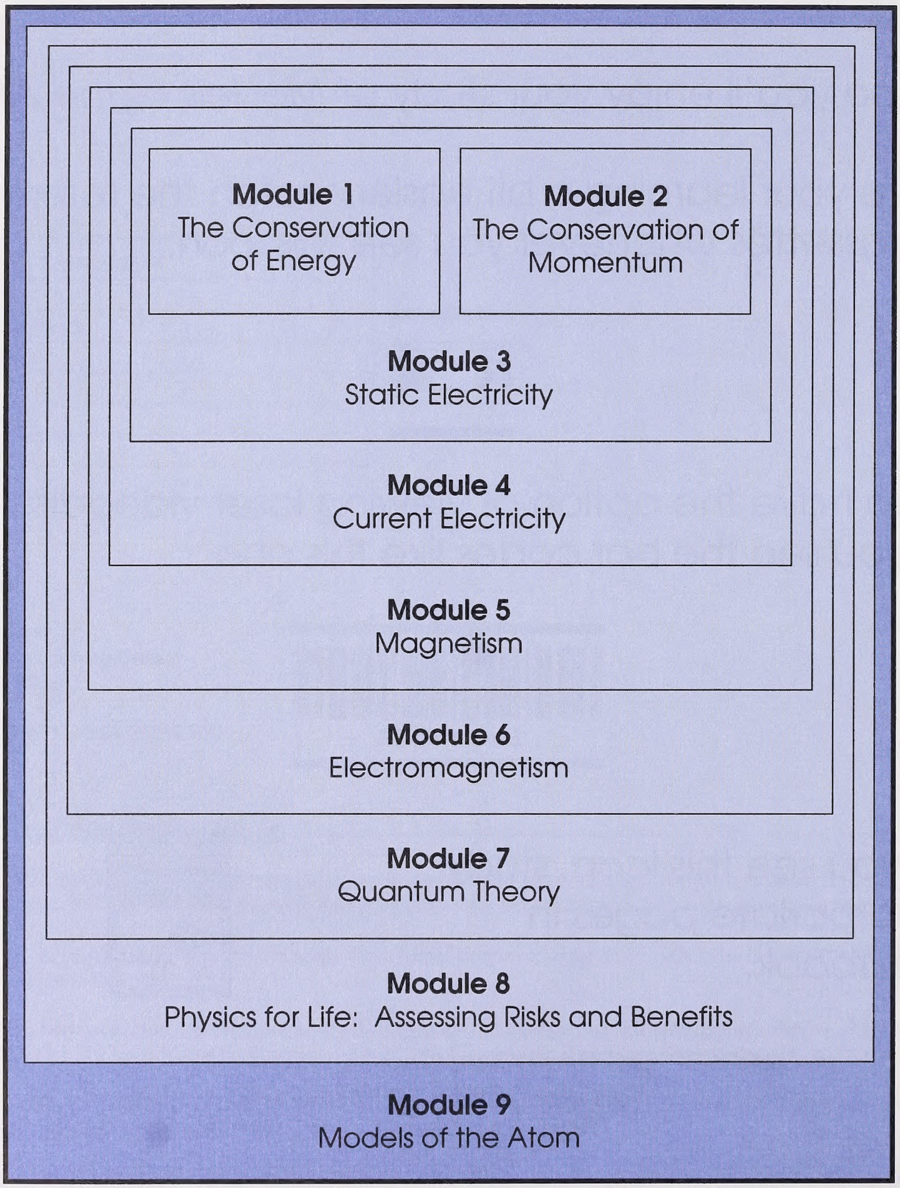
Good Luck!

Course Overview

This course contains nine modules. The first two modules develop the conservation laws of energy and momentum. The conservation of energy is at the heart of the entire course. Modules 3 through 9 build one upon the other and incorporate the main ideas from the preceding modules.

The module you are working in is highlighted in a darker colour.

PHYSICS 30



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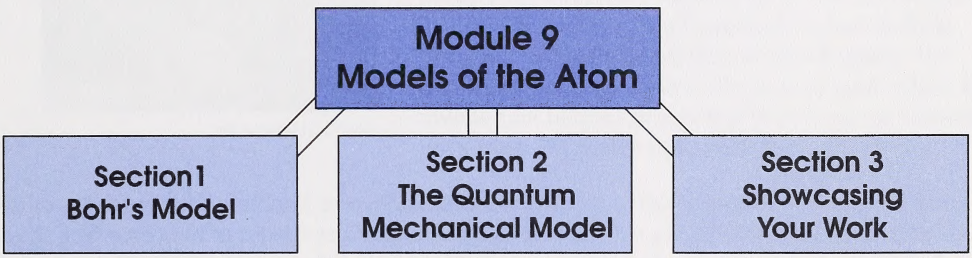
OVERVIEW

Imagine that you are travelling with friends down a rural highway in the middle of the night. Despite the late hour, there is a buzz of anticipation in the car because you have almost reached your destination. The sky is lit by the glow of all the lights from a very large city.

It's not long before you are driving through the city centre, where your eyes are treated to a stunning display of light from all the signs that line the streets. After travelling for hours through the dark countryside, you are especially sensitive to the deep, vibrant colours produced by the neon signs.

Have you ever wondered how neon signs produce single colours of light so brilliantly? It might surprise you to know that these rich colours originate from an energy transfer that occurs within individual atoms.

In this module you will investigate the light that is emitted from particular atoms. You will then apply several key ideas from previous modules as you develop a model for understanding the behaviour of atoms. These topics will finally merge with a review of the whole course as you prepare for the diploma exam.



Evaluation

Your mark in this module will be determined by your work in the Assignment Booklet. You must complete all assignments. In this module you are expected to complete three section assignments. The mark distribution is as follows:

Section 1 Assignment	36 marks
Section 2 Assignment	30 marks
Section 3 Assignment	34 marks
TOTAL	**100 marks**

Section

1 Bohr's Model

THE BETTMANN ARCHIVE

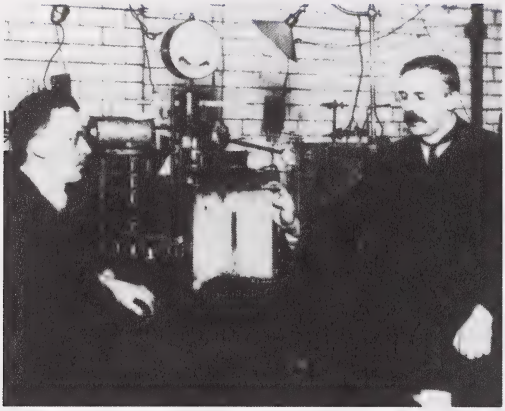
In 1943 a small British aircraft flew over the North Sea in great secrecy. A passenger was being smuggled from Sweden to England. The aircraft was so small that the passenger had to lie in the belly of the aircraft tightly wrapped in blankets and a sleeping bag. It was crucial for the allied war effort to safely deliver this brilliant physicist from the hands of the Nazis. Suffering from lack of oxygen and hypothermia, he likely thought about the events of the previous years as he waited out the flight. His native country of Denmark was invaded and then occupied by the Germans in 1940. Since he did not cooperate with the occupying forces, he was forced to flee to Sweden in 1943. Before leaving Denmark he had to hide the gold Nobel Prize medals of two friends. He dissolved the medals in a large jar of acid. Once in Sweden he helped to arrange the escape of Danish Jews from the terror of the Nazis.

Although he nearly perished from the harsh conditions in the aircraft, he survived the flight and was able to return to Denmark after the war. He precipitated the gold from the acid and had the two medals recast. More importantly, he directed a great deal of energy towards the development of peaceful uses of nuclear power.

This story is not fiction. It is a chapter in the life of a kind and gentle man who made remarkable contributions to the present understanding of the atom. His name was Neils Bohr. Neils Bohr developed his model for the hydrogen atom early in his career (in 1913) and it changed the way physicists thought about the atom forever.

In this section you will trace the development of Bohr's model of the hydrogen atom. You will begin by analysing the experimental work that led to the idea that an atom should have a nucleus. You will then use observations from the light emitted by different atoms as a bridge to the development of Bohr's model. Finally, you will investigate Bohr's theory with concepts learned earlier in the course to derive equations that describe Bohr's hydrogen atom.

Activity 1: Rutherford's Nuclear Atom



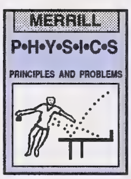
Hans Geiger and Ernest Rutherford THE BETTMANN ARCHIVE

Ernest Rutherford grew up on a farm with his eleven brothers and sisters in New Zealand. Although he did very well in school, and later at New Zealand University, it took a few lucky breaks for Rutherford to be able to work under J.J. Thomson at Cambridge University in England.

The first bit of luck was that Cambridge University had just changed its rules about accepting students from other universities. The second bit of luck was that when a scholarship was offered to attend Cambridge, the winner turned it down, allowing Rutherford, who finished second, to make the long voyage by ship from New Zealand to England.

Once at Cambridge, Rutherford began to work in the exciting new field of research known as radioactivity. In 1900, after five years of research, Rutherford had helped name the radioactive emissions *alpha*, *beta*, and *gamma*.

Rutherford's most significant contribution to science came as an extension of his interest in alpha particles. In 1906, at McGill University in Montreal, he began studying how alpha particles were scattered by thin sheets of metal. He continued these experiments when he returned to England. Working closely with his assistant, Hans Geiger, Rutherford used the results of his experiments to develop a new model of the atom.



Carefully read page 574 and the first two paragraphs on page 575 of your textbook to learn more about Rutherford's discovery. Be sure to examine the diagrams that illustrate Rutherford's observations.

1. Describe the model of the atom that was proposed by J.J. Thomson.

2. Draw a labelled diagram to describe the results of Rutherford's scattering experiments.

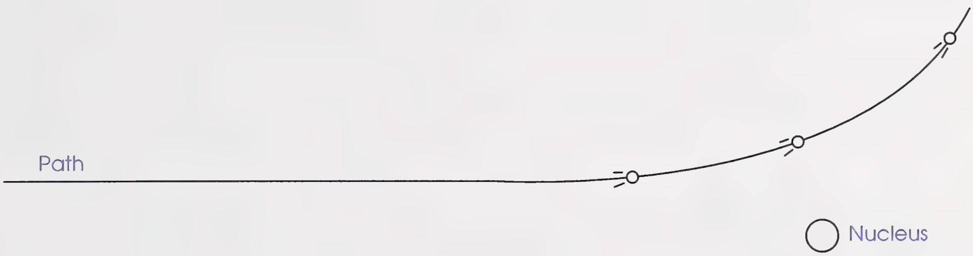
3. Why did the results of Rutherford's experiments necessitate the creation of a new model of the atom?

Check your answers by turning to the Appendix, Section 1: Activity 1.

Since Rutherford's experiment is a dynamic one – involving the interaction of moving particles – the best way for you to understand it is to see some computer animation of these interactions.

The video series *Structure of the Atom* contains a ten-minute program called *The Rutherford Model.* Familiarize yourself with the following questions prior to watching the program. This will help you focus on the main ideas while you are viewing. You may have to periodically stop the tape in order to record your answers.

4. Copy the following diagram into your notebook. Complete the diagram by drawing arrows to represent the repelling force on the alpha particle at each of the positions indicated.



5. Add to the diagram that you drew for the previous question by drawing the components of the force vectors. Note that one component should be parallel to the alpha particle's path and the other should be perpendicular to it.

6. What does the parallel component of the force do to the motion of the particle?

7. What does the perpendicular component of the force do to the motion of the particle?

8. What was Rutherford's estimate for the largest possible radius that a gold nucleus could have?

9. Although Rutherford's model was a major breakthrough, it did have some inconsistencies with electromagnetic theory.

   a. Describe the behaviour of Rutherford's nuclear atoms as predicted by classical electromagnetic theory.

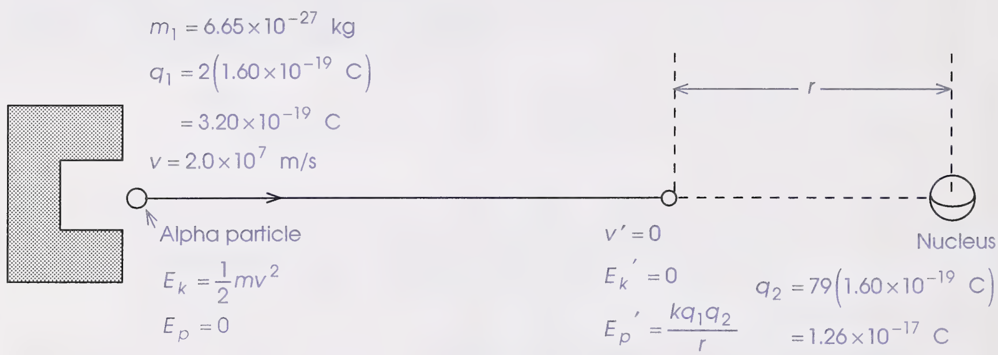
   b. What is the problem with these predictions?

Stop the video at the end of the program.

Check your answers by turning to the Appendix, Section 1: Activity 1.

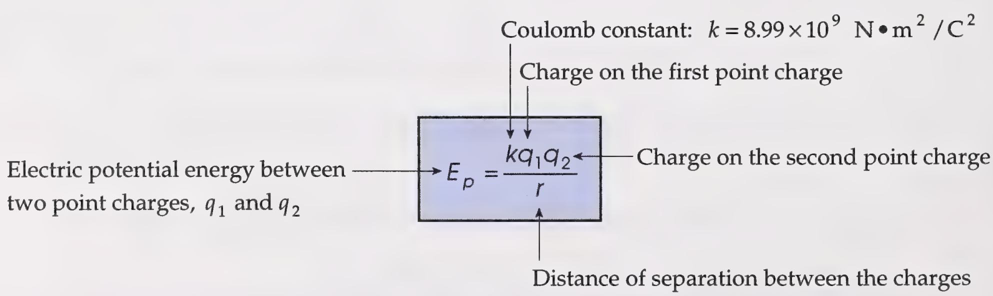
Rutherford and his assistants took years to collect and analyse the data from his scattering experiments. The mathematical techniques that they used proved that the repelling force on the scattered alpha particles was the Coulomb force (electrostatic force) and that the maximum radius for a gold nucleus was about 3×10^{-14} m. The mathematical techniques that Rutherford and his team used go beyond Physics 30; however, you can gain insight into the experiment by using a conservation-of-energy approach.

Consider the special case of an alpha particle aimed directly at the centre of the nucleus. In this special case the particle is slowed by the electric field of the nucleus until it stops. At this point the kinetic energy of the alpha particle has been completely converted to electric potential energy. After this instant the alpha particle is repelled back along its original path with the potential energy being converted back into kinetic energy. The following diagram summarizes these ideas and shows some realistic sample data.



Since the alpha particle does not strike the nucleus, the distance of closest approach (r) can be used as a reasonable upper limit for the size of the nucleus.

Before you complete the calculation, you should know a little bit about the equation for electric potential energy for two point charges.



This equation really requires calculus to derive it properly. However, an outline of its origin is provided as the first Enrichment activity at the end of this section. The thing to keep in mind right now is that this equation is a useful tool that can help you apply the

law of conservation of energy and gain insight into a number of important experiments, including Rutherford's.

10. Use the equation to determine the position where the electric potential energy between two charges will approach a value of zero.

11. Apply the law of conservation of energy to solve for the value r.

12. Explain why an alpha particle has a charge of 3.20×10^{-19} C by describing the components of an alpha particle.

13. Explain why the number 79 was used to calculate the charge on the gold nucleus. Refer to the periodic table in the Physics 30 data sheets in your answer.

Rutherford's model was very successful at accounting for the results of his alpha particle scattering experiments. The main idea here is that the atom is mostly empty space and the radius of the nucleus is only about one-ten thousandth of the radius of the whole atom.

14. If a volleyball with a radius about 10 cm was used to make a scale model of an atom, how far away would the outer edge of the atom be? What does this say about the interior of an atom?

Check your answers by turning to the Appendix, Section 1: Activity 1.

Despite the fact that Rutherford's model of the atom was very helpful in describing the small size of the nucleus, it had difficulty explaining the arrangement of the electrons in the space surrounding the nucleus.

Rutherford hypothesized that each electron orbits the nucleus in a manner similar to the way that a planet orbits the sun. The idea of orbiting electrons was necessary because if they were at rest, the electric force would pull them into the nucleus. In other words, Rutherford's model has each electron continually accelerating as the direction of its velocity vector constantly changes direction along its orbital path. As you saw on the video program, this explanation forces Rutherford's model to make two predictions that don't correspond to observations.

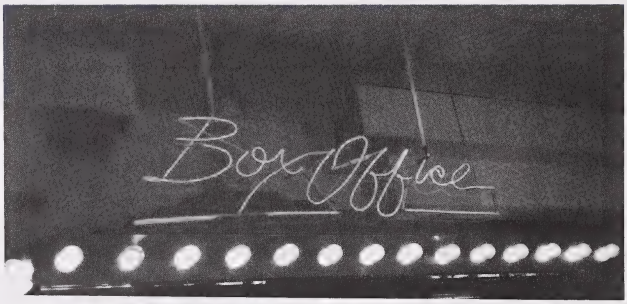
The first prediction has to do with the fact that each orbiting electron should be constantly generating electromagnetic radiation, since accelerating charges always create electromagnetic waves. The second prediction concerns the law of conservation of energy. If an orbiting electron generates energy in the form of electromagnetic waves, the electron must lose kinetic energy so that the total energy remains constant. It follows

that each electron should slow down and spiral into the nucleus as it loses kinetic energy.

How can these problems with Rutherford's model be resolved? One place to begin is to carefully observe the radiation that is actually emitted by atoms. You will have an opportunity to do this in an investigation in the next activity.

Activity 2: Fingerprinting Atoms

Have you ever been walking down a city street or through a mall and suddenly had your attention captured by the light of a very colourful sign? Sometimes these signs are the neon type. These signs often have glass tubing bent into letters to spell words. The glass tubing is filled with gas that glows brightly when high voltage is applied at the ends of the tubing. Different gases can be used to produce the different colours.



Did you know that you can identify some of elements that make up the gas in the tubing by carefully examining the light emitted? You'll have a chance to do this as you complete the investigation in this activity. You'll be surprised at what you find. What's even more surprising is that neon signs are actually misnamed because they don't all contain neon. As a matter of fact, there's one element that is found in more types of signs and lighting than any other – and it's *not* neon! You'll identify this element as a part of your investigation.

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

Your textbook contains background information about the different kinds of light that can be emitted by atoms. To help you prepare for your investigation, read the last two paragraphs on page 575 and the two paragraphs on pages 576 and 577. When you've finished reading, answer the following questions to check your understanding.

1. What is an emission spectrum?

2. How does a gas discharge apparatus produce an emission spectrum?

3. What is a spectroscope and what does it help to measure?

4. Examine the photograph on page 572 and then answer the question asked at the top of page 573 of your textbook.

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

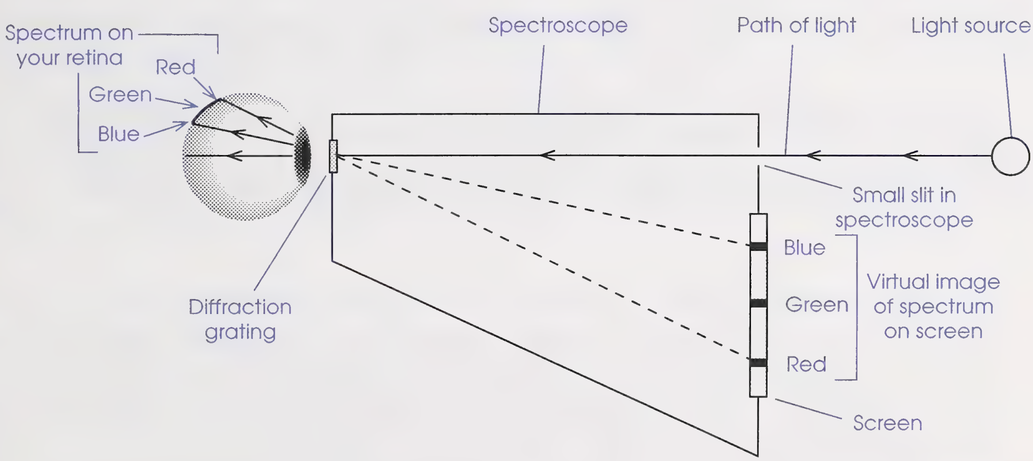
Check your answers by turning to the Appendix, Section 1: Activity 2.

A few ideas that you read about in the textbook are worth taking a closer look at because they will become crucial for the success of your investigation.

The first point is that a bright-line spectrum (emission spectrum) is created by gases that are not dense. Thin gases are created by low pressures in the gas discharge tubes. Under these circumstances the atoms of the gas are far apart, and so the light that is emitted is due to electrons interacting with **individual atoms**. The light emitted from other substances, such as solids, liquids, and dense gases, depends more on the **interactions** between electrons and groups of atoms.

diffraction grating – a piece of glass or plastic etched with thousands of parallel lines that help produce an interference pattern

The second idea is that the spectroscope that you are most likely to use uses a **diffraction grating**. The following diagram illustrates the principles behind this type of spectroscope.



The light from the light source passes through the small slit in the spectroscope and travels to the diffraction grating. The diffraction grating causes the light to separate into a spectrum of its component colours. In this case the light contained specific wavelengths of blue, green, and red light. These colours would combine to make the source look like a source of white light if your eye looked straight through the slit

toward the light source. However, if you look slightly to the side of the slit, you would be able to see the **virtual image** of the spectrum formed by the component colours. The actual spectrum is formed on the retina on the back of your eye.

The measurement of wavelength requires that the physics be summarized in the interference equations that you learned in Physics 20.

Distance from central antinode

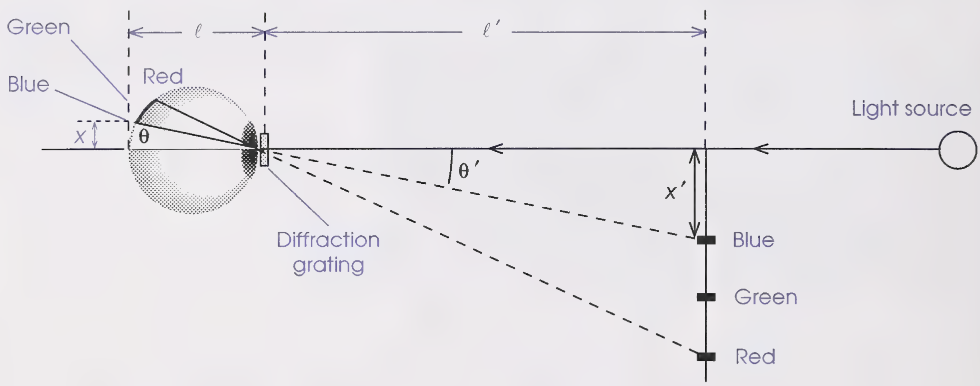
Separation of lines in grating

Wavelength of light $\rightarrow \boxed{\lambda = \dfrac{xd}{n\ell}}$ $\boxed{\lambda = \dfrac{d(\sin\theta)}{n}}$ $\leftarrow$ Diffraction angle

Order of the antinode (first, second, third, etc . . .)

Distance between grating and pattern

These variables are illustrated on the following diagram. Note that d is too small to illustrate.



Note that since the angles θ and θ' are opposite each other, the triangles containing x and ℓ and x' and ℓ' are similar. It follows that the equations will apply to the large triangle outside the eye in the spectroscope. In general, you should use the equation that uses d, θ, and n to calculate the wavelengths because it is valid for both large and small values of θ.

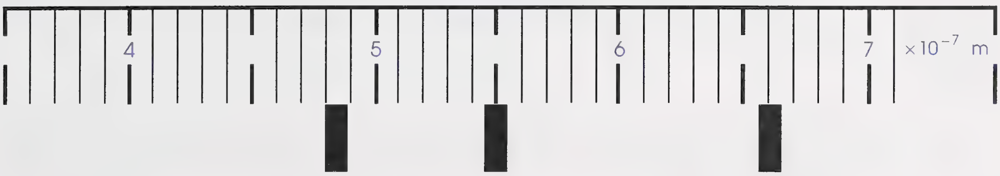
Quickly review the main ideas that support the two interference equations by reading page 392 to the top of page 395 and by reading page 400 to the last paragraph on pages 401 and 402 of your textbook. If you remember this material well, you may only

need to skim the pages, but if you are finding it difficult to understand, you should study the Example Problem and do the four Practice Problems on page 395. You can check your answers to these problems on page 679 of your textbook.

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

5. Do Problems 10, 11, and 12 on page 404 of your textbook.

The most common type of spectroscope used by Physics 30 students has a scale of wavelengths printed on the inside where the screen is. If a light source had a red line, a green line, and a blue line, as shown in the previous diagrams, you would see something like this when you looked at the screen inside the spectroscope.



The advantage of this type of spectroscope is convenience – you just point it at the light source and read the wavelengths. The disadvantage is that the scale must be placed with great care by the manufacturer, or all the wavelengths measured will be slightly smaller or larger than they actually are.

6. What are the values of the wavelengths for the red, green, and blue lines shown in the previous diagram?

7. If you were colour-blind and used this type of spectroscope, how would you know which line matched each colour?

Check your answers by turning to the Appendix, Section 1: Activity 2.

absorption spectrum – a spectrum that occurs when light has certain wavelengths absorbed as it passes through matter, resulting in a collection of dark lines

So far the only types of spectra that you have read about are the continuous spectrum, which looks like a rainbow, and an emission spectrum, which is composed of individual lines. There is another type of spectrum called an **absorption spectrum**. To learn more about this type of spectrum, read from the beginning of the last paragraph on page 577 to the start of the last paragraph on page 578 of your textbook. Pay particular attention to Figures 28-5, 28-6, 28-7, and the F.Y.I. section on page 578. The following questions highlight the key ideas on these pages.

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

8. How is an absorption spectrum produced?

9. Explain the relationship between Figures 28-5 and 28-6 on page 577 of your textbook.

10. Explain how spectroscopy can be applied in astronomy and at metal processing plants.

11. Who was Gerhard Herzberg?

Check your answers by turning to the Appendix, Section 1: Activity 2.

Now that you know how spectroscopy can be used to identify different elements present in a sample of gas, you can begin your own investigation of neon-type signs and other forms of lighting.

Investigation: Spectral Analysis of Lighting

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☑ C. Organizing
- ☑ D. Analysing
- ☐ E. Synthesizing
- ☐ F. Evaluating

Purpose

In this investigation you will first practise using a spectroscope to develop your skills of collecting and recording spectral information. In the latter part of the investigation you will apply these skills to determine some of the elements used in neon-type signs and other forms of lighting.

Materials

You will need the following materials for this investigation:

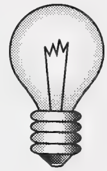
- hand-held quantitative spectroscope (has a scale inside to measure wavelengths)
- pull-out page from the Appendix of this module
- access to a light fixture that uses a standard tungsten filament light bulb
- access to a light fixture that uses fluorescent tubes
- access to a number of different coloured neon signs (These can be found in malls, large grocery stores, or in the windows of shops.)

Procedure

- Read through the entire procedure before you start the investigation. In the first part of this investigation you will practise using the spectroscope and you will calibrate it. Once you are comfortable with how to use it, you will collect and record the spectra of neon-type signs and other forms of lighting.

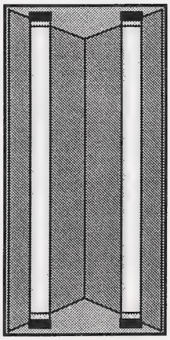
Practice and Calibration

- Find a lamp or fixture that uses a standard tungsten filament light bulb. Point the slot of the spectroscope at the bulb and look through the diffraction grating. When you stare at the slit, you should see the white light from the bulb. When you look off to the side where the scale is printed, you should see a spectrum.



12. Sketch what you see in the first space on the pull-out page in the Appendix. Label the source of this spectrum and write the colours that you see under the corresponding wavelengths.

13. What type of spectrum did the light bulb produce? What does this say about the source of the light?



- Find a fixture that uses fluorescent tubes. (If you are working at home and don't have one there, you can usually find one in any store, mall, or office.) Point the slit of the spectroscope at the tube so that the slot runs parallel to the length of the tube. You may need to move the spectroscope from side to side to see the spectrum properly on the scale.

14. Sketch what you see in the second space on the pull-out page in the Appendix. Label the source of this spectrum. If you see lines that are particularly bright, draw these in and label what colour they are.

15. What type of spectrum did the fluorescent light produce? What does this say about the source of this light?

Check your answers by turning to the Appendix, Section 1: Activity 2.

Fluorescent lights contain mercury vapour within the sealed glass tubes. This material gives off the characteristic wavelengths of light described in the following chart.

Colour of Light	Exact Wavelengths Emitted $(\times 10^{-7}\ \text{m})$	Wavelengths Seen with Hand-Held Quantitative Spectroscope $(\times 10^{-7}\ \text{m})$
Violet	4.047	4.05 This line is very difficult to see.
Blue	4.358	4.36
Green	5.461	5.46
Yellow	5.77	5.8 These two lines will look like one thick line because they are so close.
Yellow	5.79	

This means that most people will see the following three bright lines (in addition to the continuous spectrum) when they look at fluorescent lighting with a spectroscope: blue $(\lambda = 4.36 \times 10^{-7}\ \text{m})$, green $(\lambda = 5.46 \times 10^{-7}\ \text{m})$, and yellow $(\lambda = 5.8 \times 10^{-7}\ \text{m})$. However, the spectroscope that you have may give you values for wavelengths that are either slightly larger or slightly smaller than these accepted values.

16. Compare the wavelength of the bright green line described in the previous chart with the wavelength of the bright green line that you observed from the fluorescent light. Does your spectroscope tend to give readings for wavelengths that are slightly larger or slightly smaller than the accepted values?

The answer to the previous question tells you how to calibrate the readings from your spectroscope. As you complete the rest of this investigation, you will be comparing what you observe through your spectroscope with accepted values, so it's important to remember whether your spectroscope tends to produce values that are slightly higher or lower than they should be.

Exploring Neon-type Signs and Other Forms of Lighting

You will now take your spectroscope to a mall or a street with a variety of types of lighting. If the type of lighting is in a store or office, you should introduce yourself to the person in charge first, explain what you are trying to do, and ask permission. This is a matter of courtesy and will spare you possible embarrassment later. You'll be surprised how many people will ask you what you are doing – if you're shy, you may want to go when there aren't many people around. If you're an outgoing person, you'll really enjoy meeting people who are curious about your preoccupation with signs!

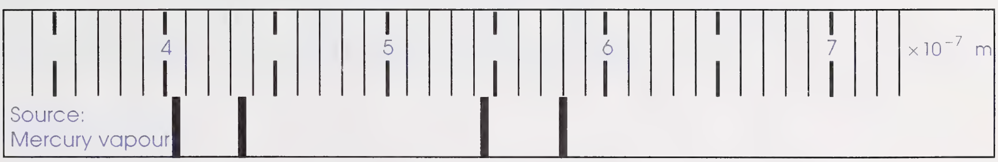
Observations

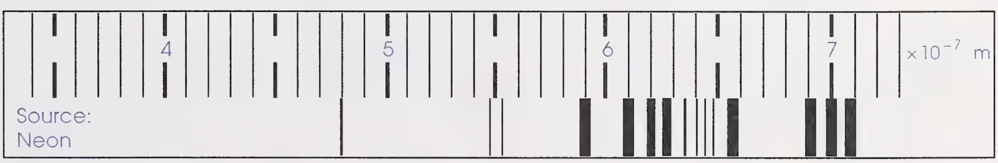
17. The following chart contains a number of different sources with suggestions for getting good results. Complete as many as possible by using your spectroscope and the pull-out page in the Appendix to record your answers.

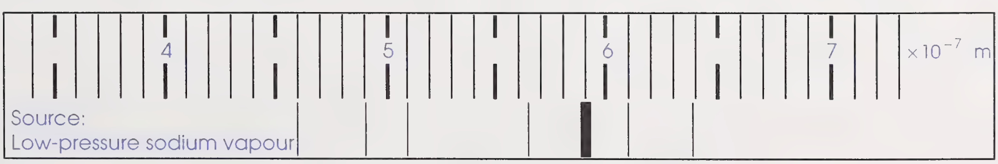
Source	Suggestions for Getting Good Results
Neon-type signs: red, orange, hot pink, green, yellow, blue, white	The glass tube can be quite thin, so it's helpful to get as close as possible. Have the slit of the spectroscope going in the same direction (parallel) as the part of the glass tubing. You may need to aim the spectroscope slightly to the side to get a clear spectrum on the interior scale.
Street lamps: white, yellow-pink, yellow-white	These usually only come on at night, so you'll have to find a way to read the scale. Pointing the spectroscope at the light from inside a car or house that has the interior light on works well. Most street lamps are the bright yellow-white type. The faint yellow-pink ones are usually only used to light turns on highways.

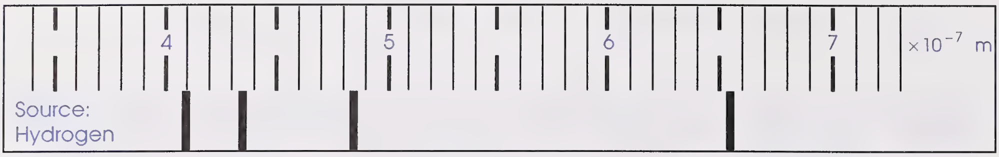
Analysis

To determine which elements are present in each type of lighting, you will need to compare your results to the following accepted values. These values were collected with a spectroscope that had no calibration errors. Note that you may have trouble seeing lines that are at the extreme ends of the scale.









Conclusions

18. Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers. Complete the chart by recording the sources that you tested and by determining which of the elements are likely to be present based on comparison with the accepted values.

Source	Element Likely to Be Present

19. Based on the results presented in your data chart in question 18, which element is most commonly found in neon-type signs?

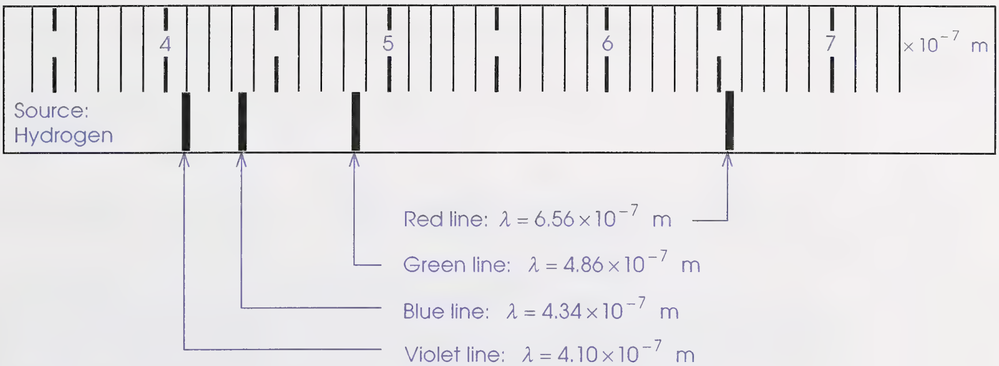
Check your answers by turning to the Appendix, Section 1: Activity 2.

When each element is put in a low-pressure gas discharge tube, it will emit a unique spectrum of bright lines. You used this fact in the previous investigation to determine some of the elements present in some common forms of lighting. Why does this occur? Does each atom have a unique internal structure that can somehow explain the emission of these lines? The answers to these questions will be the subject of the next activity.

Activity 3: Bohr's Description of the Hydrogen Atom

If the idea about the link between emission spectra and the internal structure of the atom is correct, the simplest atom should have the simplest spectrum. If you were looking for a place to start, a good thing to ask would be, "Which atom is the least complex?" Another way to ask this question is to say, "Which atom is built with the fewest parts?"

The answer is hydrogen. It is the lightest atom with the common isotope consisting of only one proton and one electron. If the idea of a link between structure and spectra is correct, this atom should have the simplest spectrum. The emission spectrum of hydrogen is shown in the following diagram.



The visible spectrum of hydrogen consists of a series of lines that are spaced closer and closer together as the wavelength gets smaller. Johann Jakob Balmer devised an equation which gave the wavelengths of these lines. The equation was developed by Balmer purely on the basis of predicting the measured wavelengths. He made no attempt to explain why it worked.

Wavelength of a line in the visible spectrum

$$\boxed{\lambda = b\left(\frac{n^2}{n^2 - 2^2}\right)}$$

n is a whole number that is different for each line: for the red line $n = 3$, for the green line $n = 4$, for the blue line $n = 5$, for the violet line $n = 6$.

This is a constant.

$b = 3.6456 \times 10^{-7}$ m

Balmer's equation is often rewritten in more modern notation as follows.

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

Reciprocal of the wavelength observed in the visible spectrum

n is a whole number that is different for each line: for the red line $n = 3$, for the green line $n = 4$, for the blue line $n = 5$, for the violet line $n = 6$.

This is a constant known as the Rydberg constant.

$$\begin{aligned} R_H &= 1.097 \times 10^7\ \text{m}^{-1} \\ &= 1.10 \times 10^7\ \text{m}^{-1} \end{aligned}$$

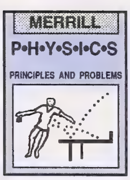
1. Use both of Balmer's equations, the original version and the modern version, to calculate the wavelength for the red line in the hydrogen spectrum.

The modern version of the equation and the Rydberg constant are both found in the Physics 30 data sheets, so this is the version that you should use throughout the rest of the module.

2. Use the modern version of Balmer's equation to calculate the wavelengths for the green, blue, and violet lines in the hydrogen spectrum.

Check your answers by turning to the Appendix, Section 1: Activity 3.

Any model of the atom should be able to account for these lines in the spectrum of hydrogen, the simplest atom. Could Rutherford's model do it? Rutherford's model was unable to account for the spectral series of hydrogen and, if electromagnetic theory was applied to it, it predicted a kind of spectrum that was never observed.



Read from the last paragraph on page 578 to the end of the second paragraph on page 580 of the textbook. Answer the following questions to help highlight the main ideas.

3. Explain the kind of spectrum that all atoms should have if classical electromagnetic theory is applied to Rutherford's model of the atom.

4. What kind of spectrum did you observe in the investigation? Under what circumstances will atoms produce this kind of spectrum?

5. What is the fate of all orbiting electrons predicted by the application of classical electromagnetic theory to Rutherford's model?

6. What two ideas did Neils Bohr try to unite and why was it considered courageous at that time?

Check your answers by turning to the Appendix, Section 1: Activity 3.

postulate – an essential starting idea that must be assumed to be true

stationary state – an allowed orbit in which an electron does not radiate energy

Neils Bohr constructed a theory that used quantum ideas to explain the emission spectrum from a nuclear atom. Bohr's theory is based on three **postulates**.

Bohr's First Postulate

An atom can be regarded as a system that can exist in any one of several energy states in which no radiation will be emitted. Even though the electrons are continually accelerating as they orbit the nucleus, no radiation is emitted. These energy states are called **stationary states**.

Bohr's Second Postulate

The emission or absorption of radiation by an atom occurs when there is a sudden transition between two stationary states. The energy of the radiation emitted corresponds to the energy difference between the initial and final stationary states.

$$\boxed{E_{light} = \Delta E_{atom}} \Rightarrow \boxed{hf = E_i - E_f} \Rightarrow \boxed{\frac{hc}{\lambda} = E_i - E_f}$$

The wavelength of a photon that is absorbed or emitted

Bohr's Third Postulate

The electron can only occupy certain stable orbits. These orbits must satisfy the following equation:

Speed of electron

Number of orbit $n = 1, 2, 3, 4, \ldots$

Mass of electron

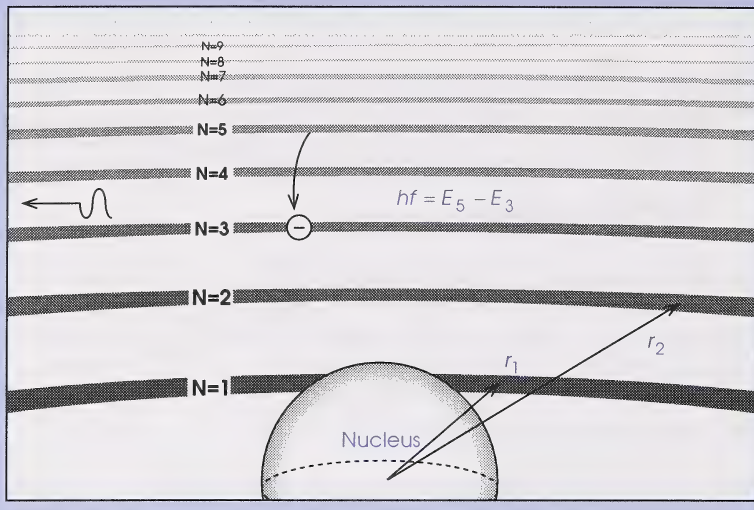
$$\boxed{mvr = n\frac{h}{2\pi}}$$

Planck's constant $h = 6.63 \times 10^{-34}$ J•s

Radius of orbit

You'll learn more about this equation later in the module. It is shown here now to help make a point about how Bohr's theory of the atom has key values quantized.

Diagram to Summarize Bohr's Three Postulates



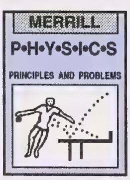
Bohr's Module for Hydrogen:

- The electron can only occupy certain orbits: $r_1, r_2, r_3, \ldots$
- Each orbit has its own energy level: $E_1, E_2, E_3, \ldots$ These energies can have only certain values.
- When an electron moves between orbits, the energy of the associated radiation can have only certain values which are equal to the energy change.

You can see that Bohr's theory uses quantum ideas extensively because the following three things are all quantized:

- radius of an electron's orbit
- energy level of an electron's orbit
- energy of photons absorbed or emitted

It will take some time and work on your part to really understand how Bohr's model works. A good place to begin is your textbook.



Read from the third paragraph on page 580 to the end of the third paragraph on page 581 in the textbook. The following questions will help you identify the main ideas.

7. What is the ground state?

8. What is an excited state?

9. Why do energy levels that are further from the nucleus have more energy than those levels that are closer?

10. What occurs when a hydrogen atom emits light? Refer to the law of conservation of energy and Einstein's equation $E = \frac{hc}{\lambda}$ in your answer.

Check your answers by turning to the Appendix, Section 1: Activity 3.

Figure 28-13 on page 582 of your textbook is very helpful for explaining the emission spectrum of hydrogen. Note that the bottom of the figure shows the four visible lines. According to this diagram, all four lines are due to electrons dropping from higher energy levels down to the second level, E_2.

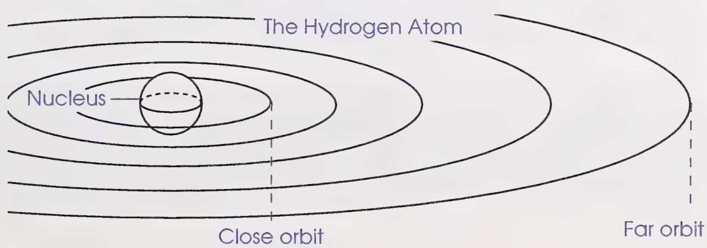
11. Which transition shown will involve the smallest change in energy? Explain why this transition should produce a photon of light with the longest wavelength (red).

12. Which transition shown will involve the largest change in energy? Explain why this transition should produce a photon of light with the shortest wavelength (violet).

Now that you've used the textbook to get a good start at understanding Bohr's model, it's time to use the capabilities of computer animation to help you visualize Bohr's model in action.

The video series *Structure of the Atom* contains a ten-minute program called *The Bohr Model*. Familiarize yourself with the following questions prior to watching the program. This will help you focus on the main ideas while you are viewing. You may need to periodically stop the tape in order to record your answers.

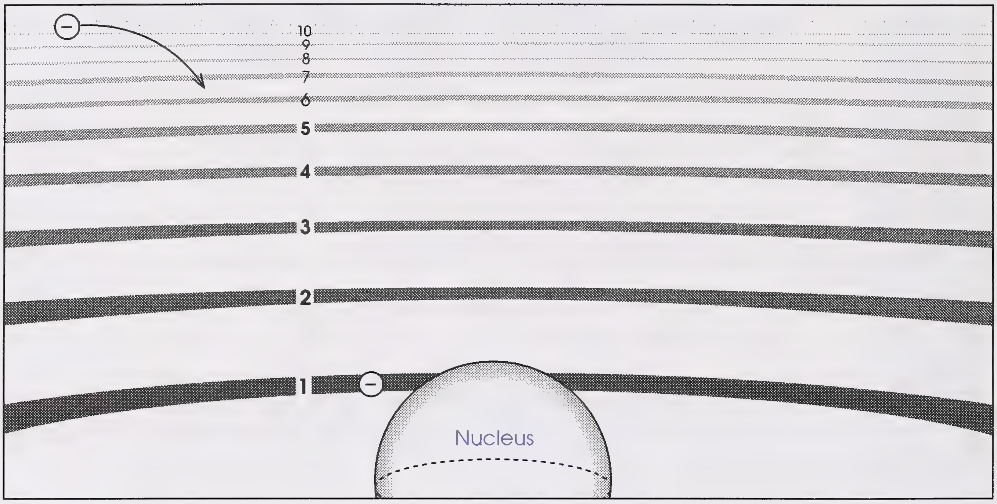
13. Copy the following diagram into your notebook. Be careful to leave enough space to record your answers. Complete the diagram by drawing arrows to indicate the size of the attractive force at both locations, close orbit and far orbit. Also indicate where the electron has less energy and where it has more energy.



14. Add an arrow and a label to your diagram to show which way work must be done to move an electron within the hydrogen atom.

15. How many energy levels does a hydrogen atom have?

16. Copy the following diagram into your notebook. Be careful to leave enough space to record your answers. Complete the diagram by labelling the conditions needed for an orbiting electron to make the transition from the ground state to the first excited state.



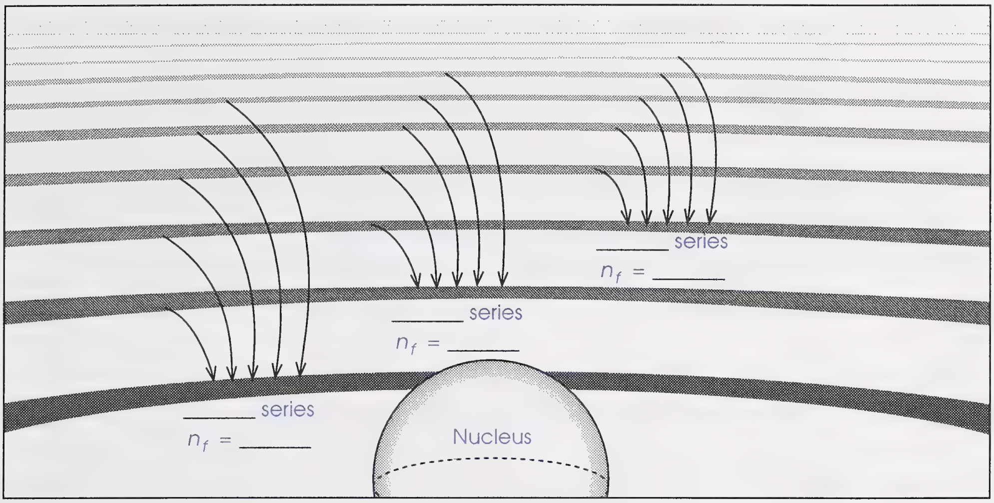
Check your answers by turning to the Appendix, Section 1: Activity 3.

The next video program uses computer animation to show how Bohr's model accurately predicts the spectrum of hydrogen.

The video series *Structure of the Atom* contains a ten-minute program called *Spectra*. Familiarize yourself with the following questions prior to watching the program. This will help you focus on the main ideas while you are viewing. You may have to periodically stop the tape in order to record your answers.

17. So far you have just considered the visible series of lines that are emitted from hydrogen. This series of lines is named the Balmer series after the person who did the initial work in studying this series of lines. Name two other series of lines and identify the regions of the spectrum where they can be found.

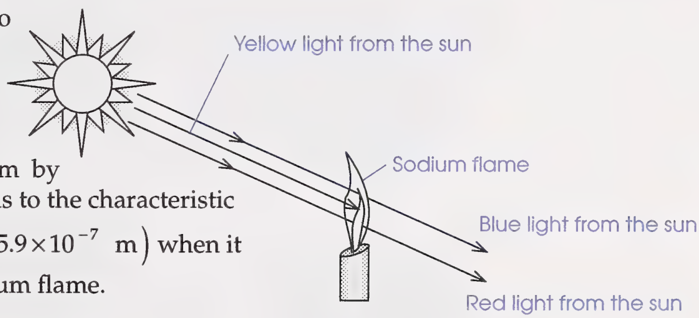
18. Copy the following diagram into your notebook. Be careful to leave enough space to record your answers. Complete the diagram by naming each series of lines and by labelling the final energy level.



19. Explain why it makes sense that the Lyman series is in the ultraviolet region of the spectrum while the Paschen series is in the infrared region of the spectrum. Refer to the previous diagram in your answer.

20. What does every line in the hydrogen spectrum correspond to?

21. Copy this diagram into your notebook. Be careful to leave enough space to record your answers. Complete the diagram by showing what happens to the characteristic sodium wavelength $(5.9 \times 10^{-7}\ \text{m})$ when it passes through a sodium flame.



22. Explain why it is incorrect to say that the sodium flame in the previous diagram completely removes light with a wavelength of 5.9×10^{-7} m.

Check your answers by turning to the Appendix, Section 1: Activity 3.

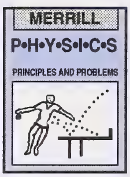
Activity 4: Bohr's Equations for the Hydrogen Atom

Up to this point the exploration of Bohr's model of the hydrogen atom has focused largely on what his postulates mean and how these ideas relate qualitatively to the spectrum of hydrogen. It's now time to take a quantitative approach and use equations and known values to calculate some of the important quantities that define the hydrogen atom. After all, Bohr's model predicts that radius, energy levels, and emitted wavelengths of light should all be quantized. Shouldn't it be possible to use calculations to predict what these allowed values should be?

quantum number – the number of each of the allowed orbits; $n = 1, 2, 3, 4, \ldots$

This activity will be spent deriving key equations that describe the quantum nature of the hydrogen atom. In each case the constant n is a whole number called the **quantum number**. The quantum number refers to the number of the energy level.

Radius Is Quantized: $r_n = n^2 r_1$



Read from the beginning of the fourth paragraph on page 581 to the middle of page 582 of your textbook to learn how an equation for the allowed radius of the hydrogen atom can be derived. When you have finished reading, answer the following questions which are based on the derivation.

1. The following flow chart shows the beginning of the derivation of $r_n = n^2 r_1$, where $r_1 = 5.29 \times 10^{-11}$ m. Complete the derivation by carefully showing all steps. Add the necessary comments to help explain the procedure at each step. Be sure to use the values from the Physics 30 data sheets when you substitute for the constants.

$F_e = F_c$ — The electric force provides the centripetal force for the orbitting electron.

↓ Substitute.

$$\frac{kq^2}{r_n^{\,2}} = \frac{mv^2}{r_n}$$

$mvr_n = \frac{nh}{2\pi}$ — Bohr's third postulate

↓ Rearrange.

$v =$

↓ Square both sides.

[ ]

↓ Substitute.

[ ]

2. Use a ruler to complete a scale drawing of the first five orbits in the hydrogen atom. Let r_1 be represented by a 5-mm space on your sketch.

3. If you were asked to sketch the tenth energy level on your scale drawing, how far from the nucleus would it be? Would it fit on your page?

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4. Do Practice Problems 1 and 2 on page 583 of your textbook. Use the equations and constants found in your Physics 30 data sheets.

Check your answers by turning to the Appendix, Section 1: Activity 4.

Note that the value of r_1 calculated from the constants in the Physics 30 data sheets is slightly larger than the accepted value of 5.29×10^{-11} m. This discrepancy is due to rounding off the Physics 30 constants to three significant digits. If the constants used were precise to four significant digits, the calculation would give the accepted value of r_1.

Speed of the Orbiting Electron Is Quantized: $v_n = \frac{v_1}{n}$

The derivation of this equation is based on using some of the results from the last derivation. The following flow chart shows how to start the derivation from the main ideas.

Bohr's third postulate

$$mv_n r_n = \frac{nh}{2\pi}$$

Rearrange.

$$v_n = \frac{nh}{2\pi m r_n}$$

Substitute.

From the derivation of $r_n = n^2 r_1$

$$r_n = \frac{n^2 h^2}{4\pi^2 mkq^2}$$

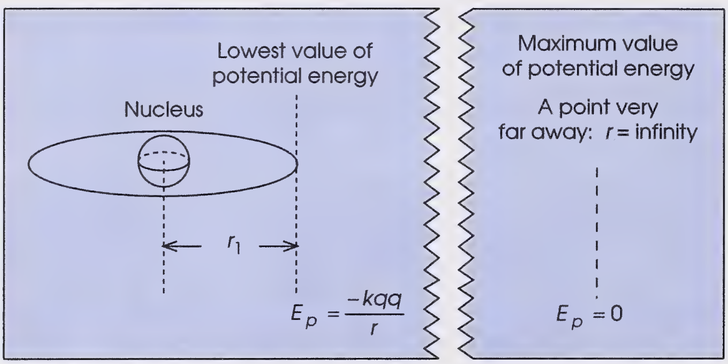
5. Complete the derivation of $v_n = \frac{v_1}{n}$, where $v_1 = 2.18 \times 10^6$ m/s, by carefully showing all the necessary steps. Add the necessary comments to help explain the procedure at each step. Be sure to use the values from the Physics 30 data sheets when you substitute for the constants.

6. Calculate the speed of the electron in the second, third, and fourth allowed Bohr orbits of the hydrogen atom.

Check your answers by turning to the Appendix, Section 1: Activity 4.

Energy Levels Are Quantized: $E_n = \frac{E_1}{n^2}$

This equation is the most complicated to derive because it requires some thought about the potential energy that exists between the hydrogen nucleus (proton) and the electron. The following diagram describes the essential conditions.



Since work must be done to move an electron from a position close to the nucleus to one far away, potential energy is at a maximum when the electron is infinitely far from the atom. But it's also set to zero at this location according to the equation $E_p = \frac{kqq}{r}$. How can zero be the maximum value for potential energy?

The solution is to give the potential energy negative values close to the atom. Using this system, the potential energy can still have its lowest values close to the atom, and as you move further from the nucleus, the values gradually increase until they reach the maximum value of zero. This is why the negative sign is included in the potential energy equation.

The derivation can now proceed using the law of conservation of energy.

$$\begin{bmatrix}\text{Total energy of the atomic}\\ \text{system (nucleus + electron)}\end{bmatrix} = \begin{bmatrix}\text{Kinetic energy of}\\ \text{the orbitting electron}\end{bmatrix} + \begin{bmatrix}\text{Potential energy}\\ \text{of the atomic system}\end{bmatrix}$$

From the derivation of $v_n = \frac{v_1}{n}$:

$$v_n = \frac{2\pi kq^2}{hn}$$

$$E_n = E_k + E_p$$

Substitute.

$$E_n = \frac{1}{2}mv_n^{\,2} + \frac{-kqq}{r_n}$$

From the derivation of $r_n = n^2 r_1$:

$$r_n = \frac{n^2h^2}{4\pi^2 mkq^2}$$

Substitute.

Substitute.

$$E_n = \frac{1}{2}m\left(\frac{2\pi kq^2}{hn}\right)^2 + \frac{-kqq}{\left(\dfrac{n^2h^2}{4\pi^2 mkq^2}\right)}$$

7. Complete the derivation of $E_n = \frac{E_1}{n^2}$, where $E_1 = -13.6\ \text{eV}$, by carefully showing all the necessary steps. Add the necessary comments to help explain the procedure at each step. Be sure to use the values from the Physics 30 data sheets when you substitute for the constants.

8. Calculate the energies of the second, third, and fourth allowed Bohr orbits of the hydrogen atom.

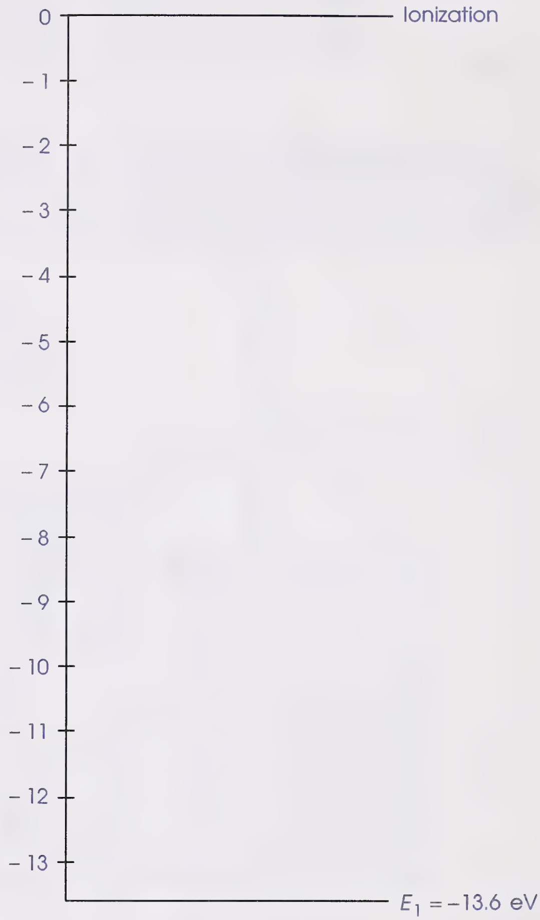
Check your answers by turning to the Appendix, Section 1: Activity 4.

You can see from the previous derivations that Bohr's model not only explores the observed behaviour of hydrogen, it also predicts the allowed radii and energy levels of the hydrogen atom. The final test is to see whether or not these equations work. Can these equations make predictions that can be tested by observation? The best observations for such a test are the visible lines in the hydrogen spectrum. After all, it was these lines that led Bohr to his model in the first place!

The following questions are designed to help you bring it all together as you calculate values for each of the visible lines in the hydrogen spectrum.

9. a. Copy the energy-level diagram to the right into your notebook. Be careful to leave enough space (10 cm) beside the chart to record energy levels. Note that the vertical line is exactly 13.6 cm long so that each energy level can be measured and conveniently placed on the energy-level diagram (1 cm = 1 eV).

Energy-level Diagram for Hydrogen



b. Calculate the values of the first six energy levels and place them in the proper positions on the energy-level diagram with a ruler. Be sure to extend a horizontal line for each energy level and to label each level properly. You can use your answers from question 8 to help save time.

10. Use Figure 28-13 on page 582 of your textbook to determine which transitions cause the emission of the four visible lines in the hydrogen spectrum. Label these transitions on your energy-level diagram.

11. Calculate the wavelength of the red line by completing the following steps.

a. Determine the change in energy for this transition. Express your answer first in electron volts and then in joules.

b. Calculate the wavelength of the light that would be emitted.

12. Repeat the process used in the previous question to calculate the wavelength of the green, blue, and violet lines.

13. Compare your answers for the previous two questions to the accepted values shown in Figure 28-8 on page 578 of your textbook. If your wavelengths differ significantly, double-check your calculations. How do you account for any differences?

14. How do you account for the fact that the lines bunch up at the violet end of the spectrum? Refer to your energy-level diagram for hydrogen in your answer.

15. How many possible lines are there in the Balmer series?

16. What is the wavelength of the shortest possible line in the Balmer series? Support your calculations with a statement that refers to your energy-level diagram.

Check your answers by turning to the Appendix, Section 1: Activity 4.

As the answers to the previous questions indicate, Bohr's model was very successful for explaining the spectrum of the hydrogen atom. Bohr's model of the hydrogen atom was a very bold and creative achievement. Many of the ideas from Bohr's model are still in use today, although the present model of the atom includes many modifications to Bohr's original model for hydrogen. You'll learn more about these improvements in the next section.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you had a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

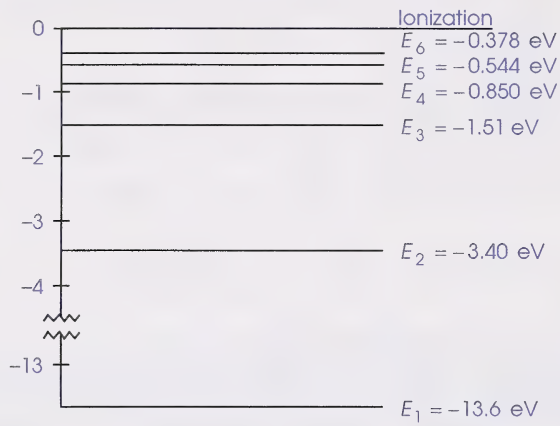
1. Imagine using a very large room (a school gym, concert hall, or large hockey arena) to represent a model for an atom. In such a model the nucleus could be represented by a single pea suspended on a thread in the middle of the room.

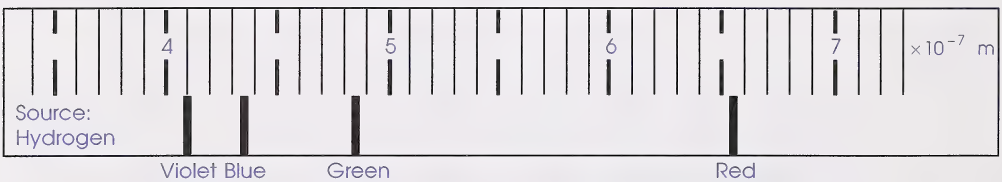
   a. What could you use to represent the electrons?

b. Use this model to explain why very few alpha particles were scattered in Rutherford's experiments.

2. The following illustration shows an energy-level diagram for hydrogen and the spectrum of hydrogen seen through a hand-held spectroscope.

Energy-level Diagram for Hydrogen





a. In terms of the energy-level diagram, what do all the lines in the visible spectrum of hydrogen have in common?

b. The red line is the first line because it corresponds to the first possible transition. What does this mean in terms of the energy-level diagram?

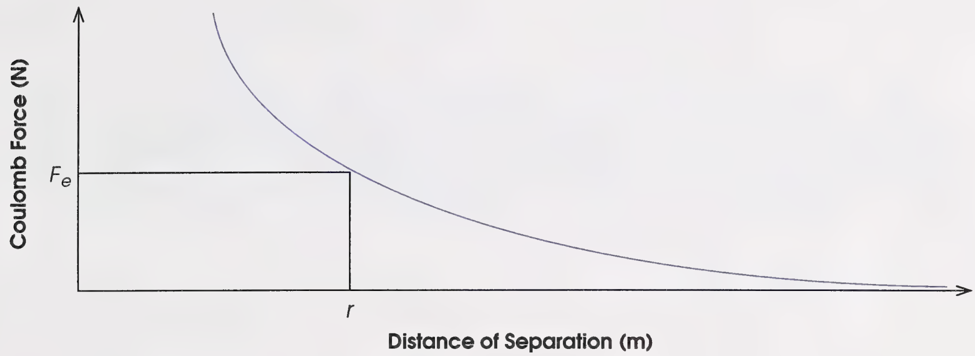
c. Calculate the wavelength of the red line from the energies shown on the energy-level diagram.

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

1. Exploring the origins of $E = \frac{kq_1q_2}{r}$

Two charges, q_1 and q_2, are separated by a distance of r, and so the force between them is given by $F_e = \frac{kq_1q_2}{r^2}$.



a. What feature of the graph would represent the work done (and therefore the potential energy of the system) in bringing the two charges from infinity to a distance of separation, r? Include a sketch of the graph illustrating this feature as part of your answer.

b. Explain why it is not convenient to calculate this work from the graph using simple geometry.

c. The branch of mathematics known as calculus includes a technique known as integration that can find the area under the curve of a known function. Here is how the calculus would be properly written.

$$\int_{\infty}^{r} F \bullet dr = \int_{\infty}^{r} \frac{kq_1q_2}{r^2} dr$$
$$= \frac{-kq_1q_2}{r} \Big|_{\infty}^{r}$$
$$= \frac{-kq_1q_2}{r}$$

How do the symbols in these calculus equations relate to the graph that was presented at the start of this question? Use resources available to you to answer this question. Resources could include a high school calculus textbook, library references, a math teacher, or an engineer in your community.

2. Why only hydrogen?

Why couldn't Bohr develop equations for atoms other than hydrogen? After all, an atom like helium only has two electrons. Surely Bohr and his colleagues could have mastered that atom as well.

The following questions are designed to give you an appreciation of what would be involved to develop equations for atoms more complex than hydrogen.

A good starting point is to realize that the derivations shown for hydrogen in the last section are greatly simplified. Part of the problem is that the Bohr model is a planetary model, just like Rutherford's.

a. Think back to your study of gravitation and Kepler's laws in Physics 20. Do planets really move in circles as they orbit the sun? Do planets maintain a constant speed throughout their orbit? What does this suggest about the planetary orbits of electrons?

b. Quickly review the derivations that you worked on in the last activity. List some of the ways that these derivations would change because of your answers to the first part of this question.

One of the main ideas that you should get from the answer to the last question is that the hydrogen atom is actually much more complex than the approach developed in Section 1. If you thought that the algebra was overwhelming then, you should see what it becomes when the answers to the previous question are considered!

So, the analysis of hydrogen using Bohr's model is far from simple. The next questions will help you to appreciate how it would be further complicated by the presence of additional orbiting electrons. Electrons can be attracted by the nucleus and repelled by other electrons. These influences occur in three-dimensional space and are constantly changing because the electrons are always moving.

c. Think back to your study of stationary charges in Module 3. Do you remember the vector treatment required to describe the forces and fields among three electrons? Next review the derivations that you worked on at the end of the last section. How would these derivations change if there was another electron orbiting the nucleus?

d. How would the derivations change if the fact that the charges were moving was considered in addition to everything else?

Check your answers by turning to the Appendix, Section 1: Enrichment.

Conclusion

In this section you have seen how Bohr's model of the hydrogen atom evolved from Rutherford's nuclear model and the study of spectra. Despite the fact that Bohr's model only applies to hydrogen, it provided a crucial stepping-stone in developing a more complete model of the atom.

In the next section you'll look at the significance of Bohr's work and you'll see how the limitations of Bohr's model led him and others to develop the present model of the atom.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

Section

2 The Quantum Mechanical Model

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When you think about the applications of quantum models of the atom, are the images that come to mind more like the top photograph or the bottom one?

The top photo shows two Canadian scientists, Dr. Brian Williams and Bernie Mason, with atom scattering equipment which is used in the analysis of surface structures. The bottom photo shows a person shopping under fluorescent lighting in a mall.

Both photographs show the applications of quantum models of the atom. After all, physics doesn't just happen in a laboratory – it's all around you.

In this section you will look at the applications of quantum theory. You will begin by evaluating Bohr's model in terms of its strengths and limitations. This evaluation will lead to an introduction to the model of the atom that is presently accepted. The section ends with a detailed exploration of fluorescent lighting. During this study, the concepts from this module will be integrated with important concepts from earlier modules, allowing you to start preparing for your final exam.

Activity 1: The Need for Quantum Mechanics

The courage that Neils Bohr showed in announcing his new model of the atom in 1913 cannot be underestimated. As a twenty-eight-year-old, who had received his PhD only two years earlier, he published a theory that basically said the physical laws that rule the world of large-scale objects do not necessarily apply to the atom. Of course many of the older physicists, who started their careers when Bohr was still in diapers, were not enthusiastic about Bohr's ideas. J.J. Thomson's opposition to this new theory caused Bohr to leave Cambridge University, where he had been working with Thomson, and move to the University of Manchester, where he worked with Rutherford.

The major triumph of Bohr's model was that it was the first reasonably successful attempt to make the internal structure of the atom explain spectroscopy and to use spectroscopic data to explain the structure of the atom. In 1922 he received the Nobel Prize for physics for his new theory. Although it was true that Bohr could not extend his model to atoms more complex than hydrogen, many of his guiding principles could be applied to other atoms in a general sort of way.

For example, although Bohr could not derive an equation for the energy levels within other atoms, he proposed that such levels did exist. More specifically, he was among the first to propose that the electrons in multi-electron atoms must exist in shells and it is the electron content of the outermost shell that determines the chemical properties of the atoms of a particular element. This whole idea of valence electrons is now fundamental to understanding basic chemistry.

Turn to your textbook and read the first two paragraphs on page 584 that summarize the successes and shortcomings of Bohr's model of the atom.

1. Describe the successes of the Bohr model.

2. Describe the shortcomings of the Bohr model.

Check your answers by turning to the Appendix, Section 2: Activity 1.

The shortcomings of the Bohr model of the atom were basically errors of omission. There were some things that the Bohr model simply could not do. The following list includes some of these things:

- When you observed spectra in the last section, you should have noticed that some hues were brighter than others. Why? The Bohr model does not address this observation. Presumably there is a greater probability of electrons making some transitions than others, but Bohr's model gives no way to calculate these probabilities.

- When a sample of a gas is heated and then placed in an electric or magnetic field, its emission spectrum shows additional lines. In a magnetic field, for instance, each line is split into additional lines. Why? There was no quantitative way to account for this in the Bohr model.

- Bohr's theory is based entirely on three postulates. Remember that a postulate is an essential starting argument that is believed to be true but is unproven. This is not a firm foundation for a theory in science. For example, why must the condition $mvr = \frac{nh}{2\pi}$ (the quantization of angular momentum) hold true? Why were Coulomb's law and Newton's laws allowed to work inside the atom while the laws of electromagnetic radiation were not?

The result of these shortcomings was that a more consistent, broadly-based, systematic theory was needed to address the things that Bohr's theory did not. Bohr himself realized these limitations and he began to work with other physicists towards the creation of an improved model.

quantum mechanics – a highly abstract, mathematical model of the atom based on the wave properties of matter

The theory that replaced Bohr's is now known as **quantum mechanics** or **wave mechanics**. As you'll see in the next activity, it began with Louis de Broglie reinterpreting Bohr's postulate that angular momentum must be quantized.

Activity 2: The Ideas of Quantum Mechanics

In a previous module you learned about a remarkable idea that Louis de Broglie developed while he was a student working toward his PhD in physics. He reasoned that if photons could have particle properties, perhaps particles could have wave properties.

When this idea was tested, electrons were found to form a diffraction pattern when scattered by crystals. The main equation that de Broglie suggested to support his ideas follows.

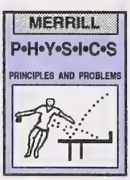
$$\boxed{\lambda = \frac{h}{mv}}$$

Wavelength of the particle → λ

Planck's constant → h

Speed of the particle → v

Mass of the particle → m



Carefully read from the bottom of page 584 to the top of page 585 of your textbook to learn how this idea can be used to reinterpret Bohr's third postulate about angular momentum.

1. Complete the following derivation of the equation $mvr = \frac{nh}{2\pi}$ by adding the missing steps.

Circumference of orbit = a whole number of electron wavelengths — Condition for standing waves

↓ Substitute.

$2\pi r = n\lambda$ — $n = 1, 2, 3, \ldots$

↓

2. How is this method of obtaining $mvr = \frac{nh}{2\pi}$ an improvement compared to Bohr's model?

Check your answers by turning to the Appendix, Section 2: Activity 2.

De Broglie's interpretation of an electron standing wave exactly fitting around the nucleus was just the beginning. Other physicists, such as Schrödinger, Heisenberg, Born, Bohr, and Dirac, began building on this idea in the mid to late 1920s. The result was the quantum mechanical or wave mechanical model of the atom.

A good overview of this work and the main ideas of this model can be found on the following video program.

The video series *Structure of the Atom* contains a ten-minute program called *The Wave Mechanical Model.* Familiarize yourself with the following questions prior to watching the program. This will help you focus on the main ideas while you are viewing. You may have to periodically stop the tape in order to record your answers.

3. Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers. Complete the chart by showing how Heisenberg and Born came to the same conclusion as Schrödinger using different methods.

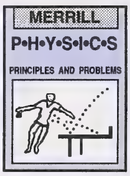
	Born/Heisenberg	**Schrödinger**
Assumptions		
Mathematics		
Conclusions		

4. The wave mechanical model states that the path taken by an electron cannot be predicted. How can the position of an electron be stated?

5. Using the idea of a cloud of electron matter waves, where are you most likely to find an electron outside a nucleus?

6. A major drawback of the Bohr model was that it only applied to hydrogen. What does the wave mechanical model apply to?

Check your answers by turning to the Appendix, Section 2: Activity 2.



The wave mechanical model of the atom has proved very useful to chemists and physicists. To learn more about the model and some of its applications, read the last three paragraphs on page 585 of your textbook. Pay particularly close attention to Figure 28-15.

7. The Bohr model of the atom compared electrons orbiting the nucleus to planets orbiting the sun. This was helpful because everyone could visualize the electron as a hard little body circling the nucleus. Why isn't such a scheme possible for the wave mechanical model?

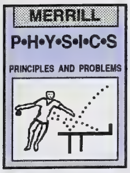
8. How has wave mechanics been used by chemists and physicists?

Check your answers by turning to the Appendix, Section 2: Activity 2.

Your textbook is actually quite concise in listing the uses of quantum mechanics. Without question, quantum mechanics has had a profound influence on your life – both in terms of advances in science and in terms of the application of this theory to create technology.

In chemistry the whole topic of chemical bonding depends on the theory of quantum mechanics. Covalent bonds, ionic bonds, and hydrogen bonds are explained in terms of quantum mechanical principles. These applications have also spilled over into biology. The theory of bonding between atoms and molecules has been applied to living systems. Topics as diverse as the formation of ATP to the process of DNA replication have been advanced by a deeper understanding of chemical bonding, which in turn depends on quantum mechanics.

Of course, physics itself has also been advanced by quantum mechanics. In particular, the study of the structure of solids, known as solid-state physics, uses quantum mechanics as a tool. The best-known application of this research is in the field of electronics. Transistors, semiconductors, integrated circuits, and computer chips could not be designed or manufactured without an understanding of quantum mechanics.



Your textbook provides a general introduction to solid-state electronics from page 594 to the top of page 599. Read these pages carefully, paying particularly close attention to Figure 29-1.

9. Explain how an **energy band** is different from an energy level. Refer to Figure 29-1 in your answer.

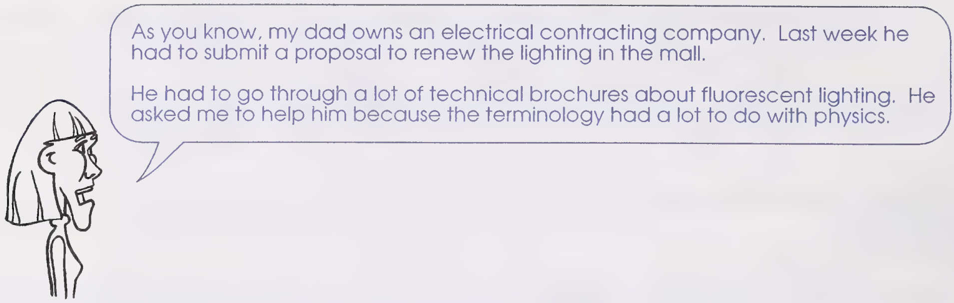
10. What is a **forbidden gap**?

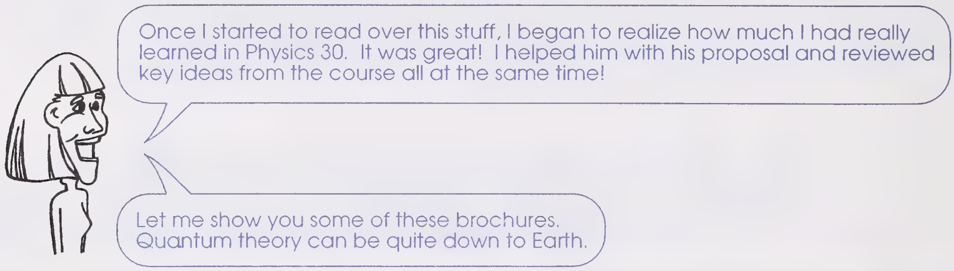
energy band – an essentially continuous band produced by the blending of energy levels from many atoms in a solid

Check your answers by turning to the Appendix, Section 2: Activity 2.

In the next activity you will have an opportunity to look in detail at a technology that uses quantum theory. This will also present a good opportunity to review a number of key concepts from earlier modules in the course.

Activity 3: Applying Quantum Mechanics





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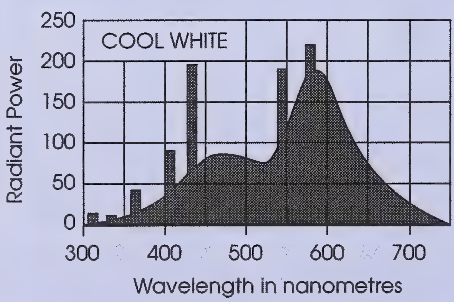
#1: Lighting Basics

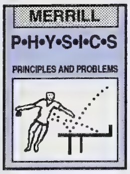


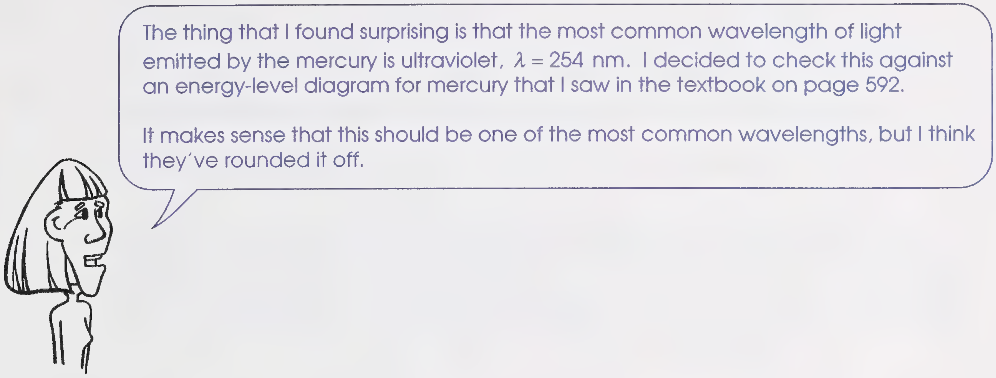
A fluoresent lamp consists of a sealed tube containing argon gas and mercury vapour at low pressure. The light from the lamp results form the excitation of the mercury in the tube.

Some of the light comes directly from the mercury atoms, while the rest comes from the phosphor crystals on the inside of the tube.

1. What kind of spectrum is represented by the vertical bars on the graph? Compare these wavelengths to the accepted values provided for the investigation in Section 1. Which atom created these wavelengths?

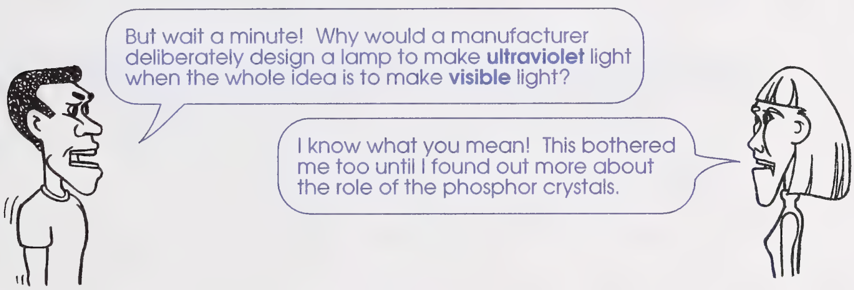
2. Note that most of the light emitted is under the continuous curving part of the graph. What kind of spectrum is that? What part of the lamp emits this light?





3. Calculate the energy of a photon with a wavelength of 254 nm. Express your answer in electron volts.

4. If you assume that the most common transition would be to the ground state, which of the energy levels likely acted as the starting point for the transition that caused this ultraviolet photon to be emitted?



fluorescence – the process of absorbing one photon or particle and then releasing a photon of lesser energy

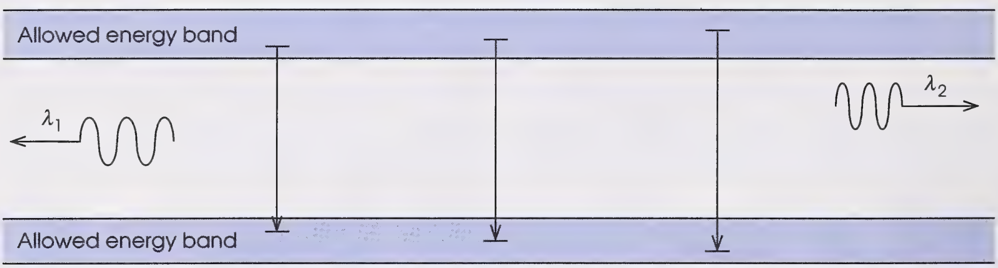
What Nicole found out is that it is essential for the phosphor crystals to be exposed to ultraviolet light if they are to emit light in the visible spectrum. This process is called **fluorescence**. The UV photon strikes a phosphor crystal, which in turn emits a photon of visible light.

It is important to note that all of the energy from the ultraviolet photon is not transferred directly to the visible light photons. The process begins with the energy of the UV photon being completely absorbed by a phosphor atom. This is a similar to the photoelectric effect in that the UV photon disappears; however, an electron within the phosphor atom does not gain all the energy of the UV photon. The fact that the phosphor atoms are part of a solid lattice of crystals means that some of the incident energy of the UV photon is transformed into thermal energy and is conducted to the rest of the atoms in the lattice. The electron in the phosphor lattice will remain excited for a

very short time and then it will drop to its normal energy band within the lattice. As with the previous transition, some thermal energy is again generated and transferred to the lattice as the electron drops back to its normal band. The thermal energy generated in this process will account for at least half of the original energy in the UV photon.

5. Explain why the released photon must have a longer wavelength than the incident UV photon, and therefore be in the visible part of the spectrum.

It is significant that the electrons responsible for the absorption and reemission of radiation within the crystals are not found in discrete energy levels. According to the ideas of solid-state physics, the electrons within the crystals are found within wider energy bands. This means that electrons in a low-energy band have a range of allowed energies within the band. The same applies to electrons in high-energy bands. The result is that when electrons make the transition to a lower band, they can emit a range of wavelengths depending on the particular starting and ending point within the allowed bands. The following diagram shows three possible transitions between two bands.



6. Refer to the previous diagram. Explain why the photon on the right must have a shorter wavelength than the one on the left.

7. Refer to the previous diagram. If the photon on the right was a green photon and the photon on the left was a red photon, what colour would you expect the photon in the middle to be?

MERRILL P•H•Y•S•I•C•S PRINCIPLES AND PROBLEMS

Turn to page 592 in your textbook and find Figure 28-23. You will need this energy-level diagram for mercury to answer question 8.

8. Suppose an electron with a kinetic energy of 7.84 eV collides with a mercury atom in its ground state.

   a. What is the maximum amount of energy that can be absorbed by the mercury atom? To what energy level will it be raised?

   b. How much energy will the electron have after the collision?

c. If the mercury atom then makes a transition back to its ground state, what wavelength of radiation will be emitted? What part of the spectrum is this photon from?

d. Suppose that the photon released by the mercury atom strikes the phosphor coating and has 64.9% of its energy converted to thermal energy of various forms by the crystal lattice. Calculate the wavelength of the single visible photon emitted by the phosphor crystals through fluorescence. What part of the spectrum is this photon from?

Check your answers by turning to the Appendix, Section 2: Activity 3.

In the previous question an incident electron caused a mercury atom to be raised to the excited energy state E_6. The mercury atom then dropped to its ground state and emitted a UV photon. This is just one possible way that the mercury atom could respond. The following two questions consider other possibilities where the mercury atom returns to the ground state in more than one step.

Again, refer to Figure 28-23 on page 592 of your textbook as you answer questions 9 and 10.

9. A mercury atom in the excited energy state E_6 drops to level E_4 and then to the ground state.

   a. Calculate the wavelength of the photon released in the transition from E_6 to E_4. What part of the spectrum is this photon from?

   b. Compare your answer from question 9. a. to the graph provided earlier (near the beginning of Activity 3) showing the spectral output of a fluorescent lamp. Where have you seen this photon before?

   c. Calculate the wavelength of the ultraviolet photon released in the transition from E_4 to E_1.

   d. The ultraviolet photon calculated in question 9. c. interacts with the phosphor coating and causes the release of a single yellow light photon with a wavelength of 5.90×10^{-7} m. How much energy must have been absorbed as thermal energy of various forms by the phosphor crystals?

10. A mercury atom in the excited energy state E_6 drops to level E_3 and then to the ground state.

    a. Calculate the wavelength of the photon released in the transition from E_6 to E_3. What part of the spectrum is this photon from?

    b. Compare your answer from question 10. a. to the graph provided earlier (near the beginning of Activity 3) showing the spectral output of a fluorescent lamp. Where have you seen this photon before?

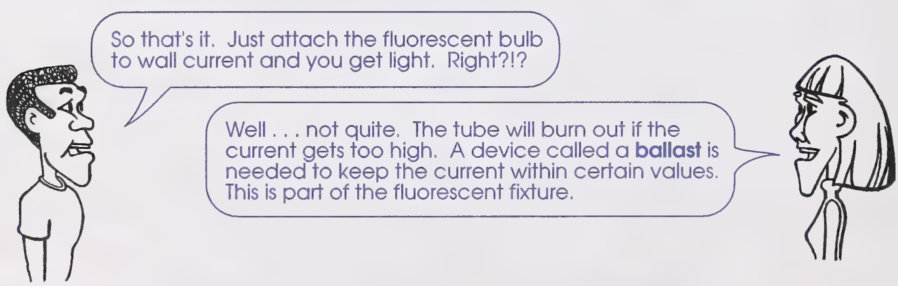
    c. Calculate the wavelength of the ultraviolet photon released in the transition from E_3 to E_1.

    d. The ultraviolet proton referred to in question 10. c. interacts with the phosphor coating, which absorbs 60.1% of the energy in various forms of thermal energy. Calculate the wavelength of the single visible photon emitted by the phosphor coating. What part of the spectrum is this photon from?

Questions 8, 9, and 10 required you to think about three different ways that a single mercury atom can make the transition from E_6 to E_1. Now switch your thinking to the big picture. Imagine the number of mercury atoms and phosphor crystals that could be excited in a 1.2-m fluorescent tube. Now try to think about all the transitions that would be simultaneously happening.

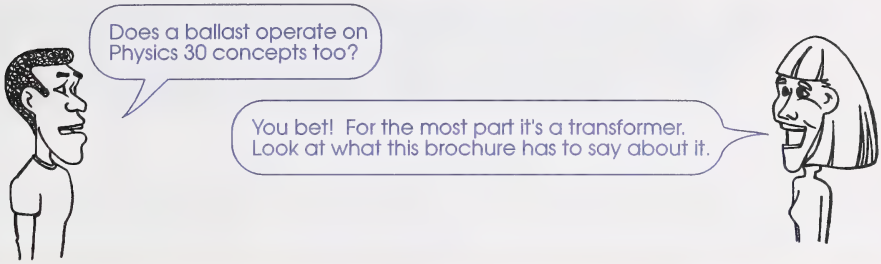
11. Briefly explain why the cylindrical walls of a fluorescent tube appear to be a source of white light.

Check your answers by turning to the Appendix, Section 2: Activity 3.



ballast – a device that stabilizes the current supplied to a fluorescent light bulb

12. The word *ballast* was originally applied to ships. Use a dictionary to determine the connection between a ship's ballast and a fluorescent fixture's ballast.



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#2: Ballasts

The ballast for a fluorescent fixture is required to perform two functions. It must provide the necessary voltage for starting and operating the lamp. The second function is to *ballast* the lamp by limiting the current to a value for which the tube is designed.

A typical fluorescent fixture with two 40-W tubes will draw 0.833 A from a 120-V supply. The ballast will supply the tubes with 0.425 A at 191 V. The ballast acts very much like a step-up transformer. It is essential to supply the ballast with the nominal input voltage of 120 V ± 5%.

Assume that the values applied in the brochure are effective or rms values.

13. Calculate the power drawn by the ballast and the power supplied to the fluorescent tube. How efficient is the ballast as a transformer?

14. Assume that the transformer in the ballast has 100 turns on its primary coil.

    a. Use the current values to calculate the number of turns on its secondary coil.

    b. Use the voltage values to calculate the number of turns on its secondary coil.

c. Explain the discrepancy between your answers for questions 14. a. and 14. b. Doesn't the transformer equation predict that the values should be the same?

Check your answers by turning to the Appendix, Section 2: Activity 3.

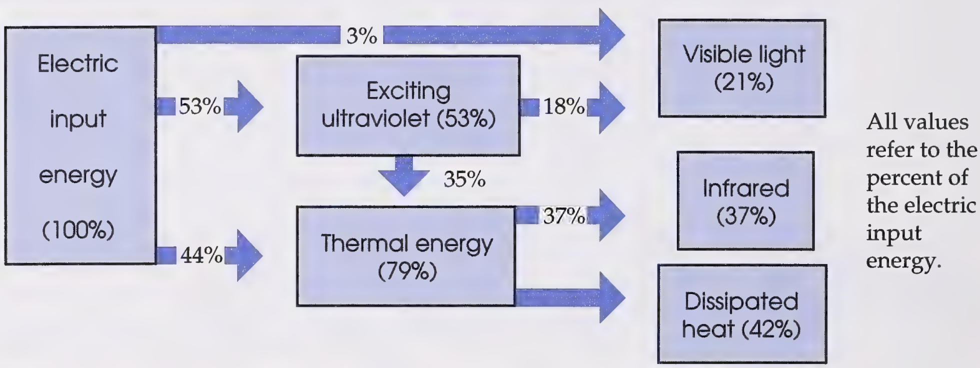
15. The two fluorescent tubes are connected in series with the ballast.

a. Draw a simple equivalent circuit that treats the ballast as a power supply and the tubes as identical resistors.

b. Label the current and voltage values supplied by the ballast to each tube.

c. Calculate the equivalent resistance of each tube.

16. The following flow chart shows how the electric input energy supplied to a cool white fluorescent tube is transformed into other forms of energy.



a. How efficient is a cool white fluorescent tube at creating visible light from the electric input energy?

b. Since the tubes are connected in series to the ballast, each one has the full 0.425 A supplied by the ballast running through it. If the tubes are identical, the voltage across each tube could be considered to be half of the supplied voltage of 191 V. Calculate the electric energy consumed by each tube per second.

c. Use your answers from questions 16. a. and 16. b. to determine the thermal energy and the light energy produced by each tube per second.

Check your answers by turning to the Appendix, Section 2: Activity 3.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

Copy the following headings into your notebook. Be careful to leave enough space under each heading to record your answers. Complete the chart by writing concise descriptions that help compare and contrast the three different models of the atom.

	Rutherford Model	Bohr Model	Quantum Mechanical Model
Identify the originator(s) of this model.			
When was this model first proposed?			
What ideas or experiments are the basis of this model?			
How does this model describe electrons?			
How are electrons arranged in this model?			
What kind of spectra are predicted by this model?			
Which atom(s) can be described by this model?			

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

1. Library Research: Phosphorescence

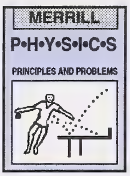
   A variety of materials, such as toys, watch dials, and paints, have a "glow-in-the-dark" capability. They will emit visible light for minutes or even hours after they are exposed to visible light. Many of these materials are said to be *phosphorescent*.

   Use the resources in a library to help answer the following questions about phosphorescent materials.

   a. What is a metastable energy state?

   b. How can these materials emit light for such a long time after their initial exposure?

2. Applying Wave Mechanics: Lasers



   Carefully read pages 586 to 590 of your textbook to discover how quantum mechanical principles have been used to develop a new light source. When you have finished reading, answer the following questions.

   a. Do Reviewing Concepts questions 6, 7, and 8 on page 592 of your textbook. Note that these questions can be found in the top left corner of the page.

   b. Do Problem 20 on page 593 of your textbook.

Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In this section you have seen how Bohr's model helped make way for the wave mechanical model of the atom.

You have also seen how the technology of fluorescent lighting is an application of the principles of quantum theory and many other concepts in Physics 30. In this way the study of fluorescent lighting helped you to review and prepare for your diploma exam.

In the next section you will take a close look at the design of the diploma exam and some strategies designed to help you be successful.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

Section

3 Showcasing Your Work

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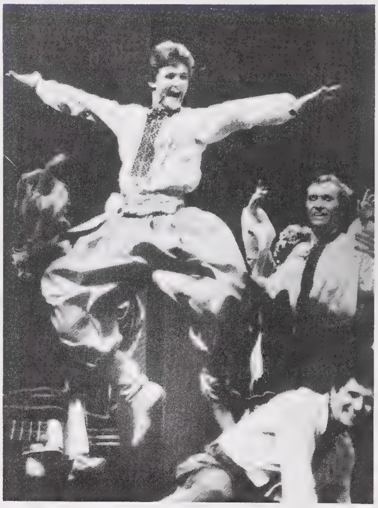

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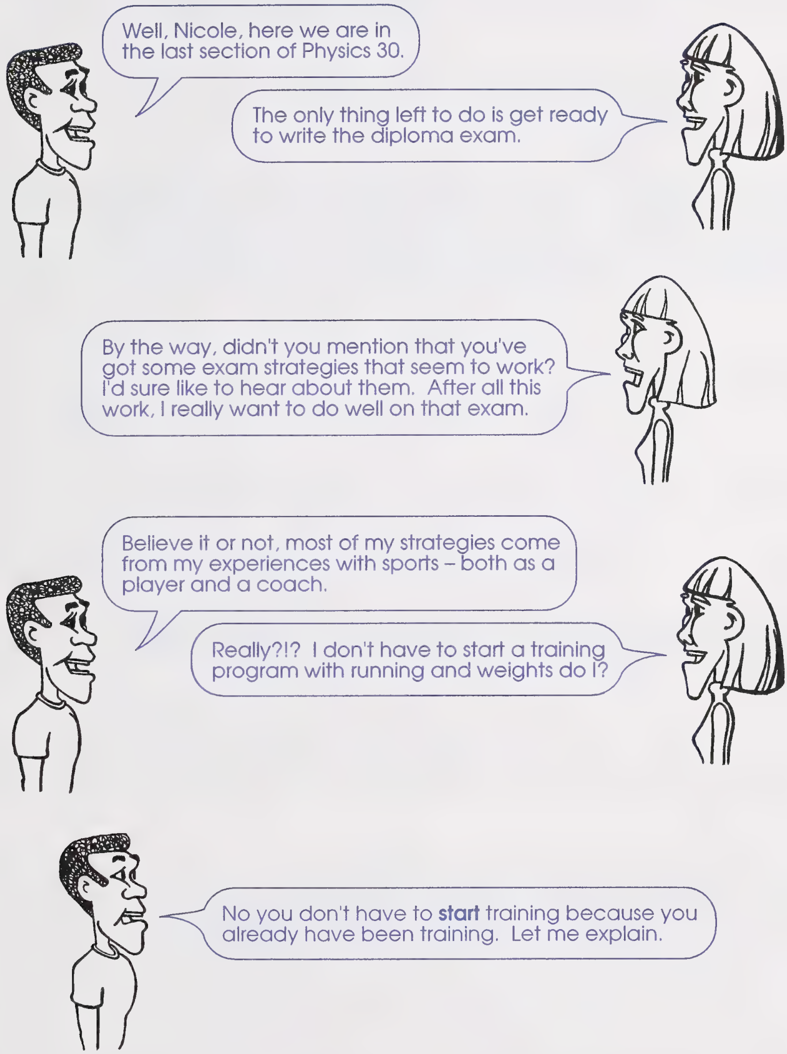
What do playing in a recital, competing in a track meet, and dancing in a performance all have in common with writing an exam? All of these events represent an opportunity to demonstrate your skills and proficiency after many hours of hard work and practice. In each case you may have a few butterflies in your stomach in the few minutes before you get started, but that's a normal reaction when you are trying to produce your top performance in an official setting. Once you get started and begin concentrating on the task at hand, the butterflies disappear and you can focus on doing your best.

One other thing that all three events have in common is that you usually have a coach or instructor to help you to prepare for the event. In addition to the coaching during the longs hours of practice, the coach will often have lots of hints for success on the day of the big event. These suggestions are often based on years of experience, so they can also give you confidence.

In this section you will get the kind of coaching that's needed to help you do your best on the Physics 30 diploma exam. You'll learn about the overall approach recommended for exam preparation and the attitude that you should cultivate as you begin to think about the exam. Next you'll examine a specific blueprint that describes the types of questions on the exam, as well as the most effective techniques for answering each type of question. You'll wrap up the section by applying what you have learned to a practice diploma exam that will act as a dress rehearsal for the real thing.

Activity 1: Attitude Counts



Mike's approach to preparing for exams is an interesting one. It's based on the idea that success in sports depends on athletes bringing the right combination of skills, preparation, and attitude to their competition. Mike's ideas apply best to individual sports, but team sports still employ many of these ideas, because teams are made up of individuals.

The focus of this strategy can be summed up in the following word equation.

Success = Personal best

Although this phrase is simple, it is really quite powerful because it can change your outlook. Rather than worrying about the other competitors, this idea focuses all available energy on the task at hand – doing better than you have ever done before. Since the only person you're really competing against is yourself, you own the event and the outcome. Ownership means that you take responsibility for the outcome and that you are in control.

1. Mike likes to compete in the high jump at track and field meets. His personal best height is 1.91 m. The next track and field meet will include a competitor who is coached by one of the assistants to the Canadian Olympic track and field team.

   a. Describe how Mike should approach the next meet.

   b. Does the presence of the other competitor affect Mike's approach?

   c. Mike competes in the track meet and jumps 1.92 m. He finishes ninth overall. Given his approach, how will he likely interpret this result?

2. What is your personal best on a major physics exam? How should you approach the upcoming diploma exam for Physics 30?

The idea of personal best implies that you will also do your best while preparing for a particular event. When Mike trains for the high jump, he lifts weights, runs distances, and does flexibility exercises. This kind of preparation helps him achieve his top performance.

3. What kind of training is required for your top performance on the Physics 30 diploma exam?

Prior to a competition, athletes will often train under the same circumstances that exist in competition. For example a high jumper might wear the same shoes and use the same distance and approach angle as in competition.

4. How could you prepare under the same circumstances as those found on the diploma exam? Be specific.

If you have ever watched Olympic high jumpers on television, you may have noticed a strange ritual that most of them do before jumping. They close their eyes, run on the spot, and pretend that they are going over the bar. Although this looks peculiar, it's been shown to improve their performance.

This process is called **visualization**. The idea is that if the high jumpers can picture doing something successfully in their mind, they will have a better chance of clearing the bar in the competition. Visualization also helps keep the athletes in a positive frame of mind, which many claim to be quite energizing. Positive thoughts are more likely to bring positive results than negative ones.

6. How can the idea of visualization be applied to your preparation for the diploma exam?

Check your answers by turning to the Appendix, Section 3: Activity 1.

The whole idea of visualization makes a crucial point. Your attitude is very important. The exam should be regarded as an opportunity for you to demonstrate all the things that you know and the skills that you have been developing.

In the next activity you'll find out specific information about the design and intent of the exam.

Activity 2: Strategies for Success

Now that you have a sense of the recommended overall approach that you should take when preparing for the exam, you are ready to look at the specifics of the exam itself. Here's a rough outline of how the questions on the exam are designed in terms of what is required to get an answer.

Type of Question	Description of Thinking Required	Approximate Percentage of Exam
Recall	remembering facts, descriptions and explanations	10%
Routine Problems	applying the major concepts from one module of the course to solve a problem. You have likely solved problems like these before.	60%
Non-Routine Problems	applying or synthesizing at least two major concepts from two different modules of the course to solve a problem. You have likely not solved problems exactly like these before.	30%

Another way to express the information presented in the chart is to say that the focus of the exam is on the big interconnecting ideas, the skills of science, and applications to society and technology. Although you need to know how these big ideas are supported by factual information, the focus is not on the facts. This fits with the description of Physics 30 given in the first section of Module 1.

1. Given the descriptions in the previous chart, how much of the exam would you expect to involve familiar concepts applied to new situations?

2. Suggest two reasons why memorizing names of scientists and equations is not a worthwhile way to prepare for the exam.

Check your answers by turning to the Appendix, Section 3: Activity 2.

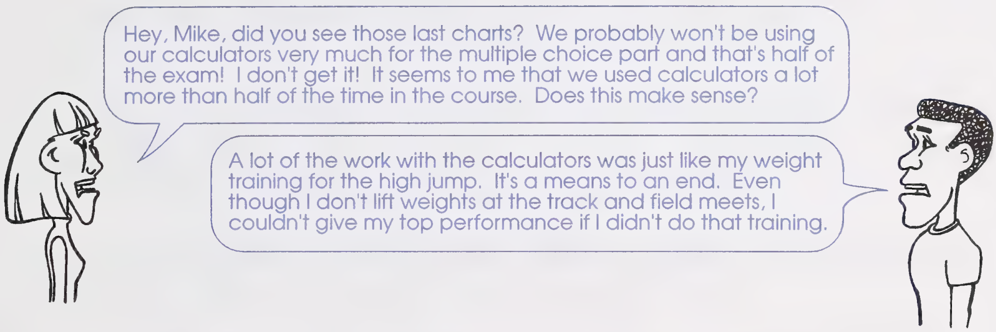
The exam can also be described in terms of the format that will be used to create the questions. The following chart summarizes the exam format in the exam year that module was printed. You should obtain current information about the exam to see if this format is still being used.

Format of Question	Description of the Techniques Used to Solve This Format of Question	Approximate Number of Questions in This Format	Approximate Percentage of the Exam in This Format
Multiple Choice	• interpreting the major concepts and their application • A calculator is likely not needed for most of these questions.	35	50%
Numerical Response	• solving routine problems • A calculator is required for each of these problems.	14	20%
Written Response	• solving non-routine problems • designing experiments • evaluating experiments • A calculator will be needed for parts of these questions.	2 or 3	30%

3. What percentage of the exam will likely not require you to use a calculator very often?

4. Which format of questions will likely require the most thoughtful and creative responses?

Check your answers by turning to the Appendix, Section 3: Activity 2.



5. In Mike's case the weight training was a means to help achieve the goal of his best performance in high jumping. What is the overall goal of Physics 30 that early work with a calculator helps to support? Refer to the two previous charts in your answer.

Check your answers by turning to the Appendix, Section 3: Activity 2.

Now that you understand the design and intent of the diploma exam, here are some very specific suggestions to help you write the exam.

Managing Time

The exam consists of questions that total 70 possible marks. In the exam year that this module was printed, students were given 180 min (3 h) to write the exam. (You should obtain current information about the exam to see if this is still the allowed time.) That works out to be about 2.5 min per mark on the exam. However, this time is just a guideline. Given the fact that the written-response part of the exam requires the most creative and thoughtful responses, you should budget more than 2.5 min per mark for this part. The chart on the next page summarizes how many students budget their time.

Format of Question	Total Number of Marks	Average Time per Mark	Total Time
Multiple Choice	35	2.5 min	90 min
Numerical Response	14	less than 2.5 min	30 min
Written Response	21	almost 3 min	60 min
	Total: 70		Total: 180 min

Given this kind of time allotment, you can see that it is a poor decision to spend 25 min answering a one-mark multiple-choice question. That would be ten times the recommended time of 2.5 min per mark! Following are some helpful strategies specifically for multiple-choice questions.

Strategies for Answering Multiple-Choice Questions:

- First read the question completely. Closely examine all the information supplied, including any charts, graphs, or labelled diagrams.
- Determine what the question is asking and then try to anticipate the answer in your mind before you begin looking at the choices.
- If the multiple-choice question involves a calculation, do the calculation. A multiple-choice calculation is usually short. If you cannot do it in 5 min, your method is either inappropriate or incorrect. Go on.
- Try to identify your answer in the choices presented. Be sure to read all the choices.
- If you can't find the right answer, try to eliminate the ones that you know are wrong. Then choose from among those remaining. It's usually better to make a choice and record an answer while the whole question is fresh in your mind, even if you have to guess. Your first choice is usually the best.
- If you would like to look at the question again, mark it and come back to it later if you have time. Only change an answer for a good reason. Do not change an answer on a hunch – first impressions are usually right.

6. Some people say that when in doubt always pick **C** because this is most often the right answer in a multiple-choice exam. Do you think that this would be valid for the questions on a diploma exam?

The numerical-response questions are different from multiple-choice questions in that you are not given any answers to choose from. In this case the answer is a number that you indicate on a special answer sheet. These questions consist of routine calculations usually involving at least two steps to get a solution. The following strategies are helpful for this format of questions.

Strategies for Answering Numerical-Response Questions:

- First read the question carefully. Closely examine all the information supplied, including any charts, graphs, or labelled diagrams. Even though it won't be scored, quickly record the relevant data.

- Determine what the question is asking. Look at the units of the answer. Begin to find helpful equations in the Physics 30 Data Booklet.

- Solve the problem with an answer that is **properly rounded to the correct number of significant digits. Record the answer as instructed on the sheet.** Do this last step carefully, as many students tend to make errors in rounding and in recording their answers.

- If you have no idea how to proceed, leave the question and return to it later. Just be sure to leave a blank on your answer sheet as well.

7. How would you answer the following question from a Physics 30 student?

   "Since the number is the only thing that matters for a numerical-response type of question, why bother to record data, equations, or any work? Why not just plug numbers straight into the calculator?"

The written-response type of question is similar to the numerical-response in that no choices are presented; however, much more is required to answer these questions than just a number. In fact, marks are awarded for the ability to communicate answers in a manner that is clear, logical, and consistent with standard conventions. This extends to graphs, vector diagrams, algebra, diagrams, paragraphs, and numerical answers (significant digits and proper units). If you have been carefully checking and correcting your work to match the answers presented in the Appendix of each module, you've been practising good communication skills. For example, this would include starting with an explicit statement of an equation **from the data sheets** and rounding to the correct number of digits only once (at the end of the problem).

The following strategies are helpful for answering written-response questions.

Strategies for Answering Written-Response Questions:

- Read the question carefully. Closely examine all the information supplied, including any charts, graphs, or labelled diagrams.

- These questions usually focus on two or more interconnecting major concepts. Begin your solution by thinking about which of the big ideas can be applied to the situation presented.

- You may not have time to write and edit a complete rough copy for each written-response question, but you should prepare an outline of your answer and use it as a guide when writing your good copy.

- When completing a written-response question, keep in mind the reader of your response. The reader will want to know how well you can understand the concepts, explain your procedure, and communicate your solution. You will be more successful if you answer in terms of what you truly know and understand than if you try to bluff by using lots of extraneous explanation.

8. What strategy is common to answering all three formats of questions?

Check your answers by turning to the Appendix, Section 3: Activity 2.

You'll have a chance to put all these strategies into practice in the next activity as you complete a practice exam.

Activity 3: A Dress Rehearsal

In this activity you'll have an opportunity to practise applying some of the major concepts from the first six modules of the course. Of course you won't be able to apply all the ideas from these modules, but you will still have a chance to review some of the big interconnecting ideas.

Spend some time studying and reviewing the first six modules now before you continue with the rest of this activity. You should find that making a study schedule as described in the first activity will help you organize your time.

The following few points will give you some tips about how to study for a physics exam.

- **Be active when you study.** Don't spend long periods of time reading the textbook or your notebook. This is not an effective way to prepare. You are better off to study in an active way. Make point-form summaries or reattempt problems from your module booklets.

- **Anticipate typical questions and try to answer them.** Using the blueprint of the exam given in the second activity, you know that the focus of the exam is on the big interconnecting ideas, the skills of science, and applications to society and technology. These are the kinds of questions that you should identify from each module. Your assignments from each section are an excellent source of typical exam questions.

- **Work within your attention span.** You know how long you can sit and be effective studying. Try to schedule your studying to take this into account. For example, if you have a whole Saturday available for studying and chores, you would be better off to alternate every two hours between studying and chores, rather than study for five hours and then do chores for five hours.

- **Stay healthy.** Studying the whole night before an exam, skipping meals, and eating junk food are definitely not good strategies. Your mind needs your body to be ready for the exam too. Use the study schedule that you developed earlier to prepare in an organized self-disciplined way, rather than a last-minute cram session.

Once you've finished studying, you should be ready to practise your test-writing strategies as you answer the following questions under exam conditions. This means that you should allot only 60 min to answer all these questions. It also means that you should have your Physics 30 data sheets, a calculator, a clear plastic ruler, some sheets of lined looseleaf paper to answer on, a pen, a pencil, and a good eraser. Pretend that this is a real exam. Arrange to be undisturbed the whole time that you are working.

Physics 30
Practice Examination

Description

Time allowed: 60 min
Total possible marks: 25

You may use your Physics 30 data sheets as a reference.

This is a **closed-book** examination consisting of **three** parts:

Part A
has **11** multiple-choice questions each with a value of one mark.

Part B
has **5** numerical-response questions each with a value of one mark.

Part C
has **1** written-response question for a total of nine marks.

Part A: Multiple Choice
11 Questions

Instructions

- Consider all numbers used in the questions to be the result of a measurement.
- Read each question carefully and decide which of the choices **best** completes the statement or answers the question.

1. The unit N•s is equivalent to the unit

   A. kg•m B. N•m C. $kg•m/s^2$ D. kg•m/s

2. The procedure of touching a charged rubber rod momentarily to a neutral electroscope is a good example of

   A. charging objects by induction

   B. charging objects by conduction

   C. charging objects by friction

   D. grounding charged objects

3. Which of the following is **not** a property of both gravitational **and** electric forces?

   A. They are both only attractive.

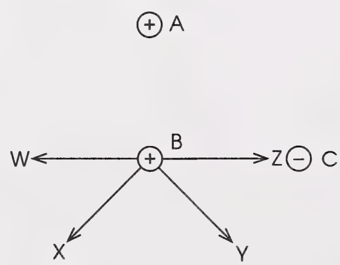
   B. They both vary inversely with the square of the distance between objects.

   C. They were both studied by Cavendish.

   D. They both require a constant to calculate their values.

Use the following information to answer question 4.

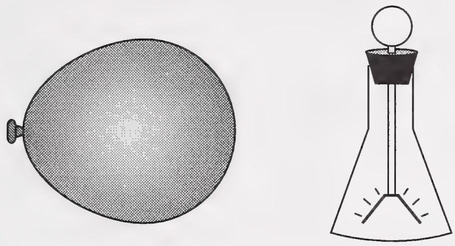
Three metal spheres with an equal magnitude of charge are situated as shown below. Each sphere is identified with the letter A, B, or C.



4. The net electrostatic force on charge B due to A and C is most closely described by vector

   A. W B. X C. Y D. Z

5. A balloon is first rubbed with fur and acquires extra electrons. The charged balloon is then held near a negatively charged electroscope, as shown below. What is the best explanation of what is observed?



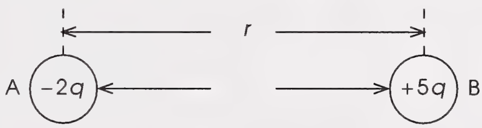
A. The leaves diverge more because the balloon has a negative charge.

B. The leaves come together because the balloon has a positive charge.

C. The leaves diverge more because the balloon has a positive charge.

D. The leaves come together because the balloon has a negative charge.

6. The charges on two identical metal objects are as shown below.



If the two metal spheres are momentarily touched together and returned to the original *r*, the charges on objects A and B respectively would be

A. neutral, $+3q$

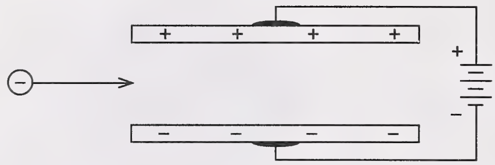
B. neutral, neutral

C. $+\frac{3}{2}q$, $+\frac{3}{2}q$

D. $+1q$, $+2q$

Use the following information to answer question 7.

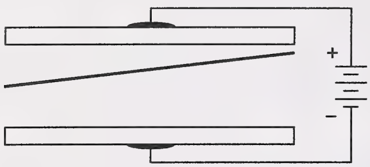
A negatively charged particle enters the region between two oppositely charged plates.



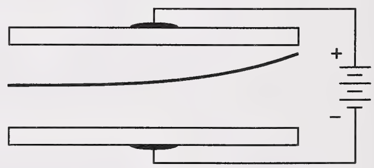
Gravitational and frictional effects can be considered negligible.

7. Which of the following best describes the path of the particle between the plates?

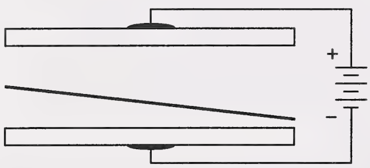
A.



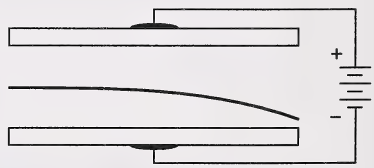
B.



C.

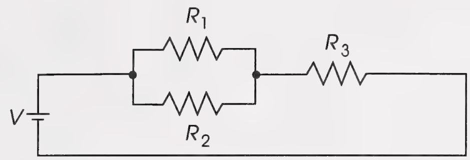


D.



Use the following information to answer question 8.

Three resistors, R_1, R_2, and R_3, are connected to a source of DC voltage as shown in the following schematic.



8. Which of the following statements correctly describes the situation?

A. Resistors R_1 and R_2 both carry the same current since they are connected in parallel.

B. Resistors R_1 and R_3 both carry the same current since they are connected in series.

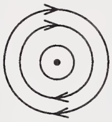
C. Resistors R_1 and R_2 both have the same potential difference across them because they are connected in parallel.

D. Resistors R_1 and R_3 both have the same potential difference across them because they are connected in parallel.

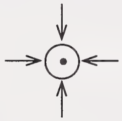
---

9. A proton is moving directly out of the plane of the page. The direction of the magnetic field around the proton is illustrated by

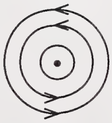
A.



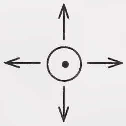
B.



C.

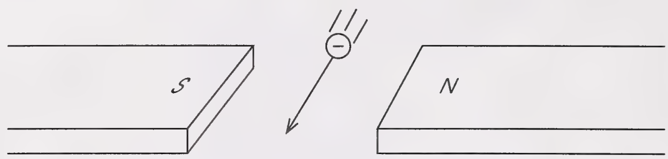


D.

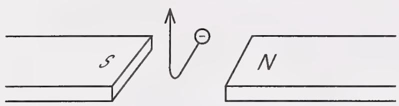


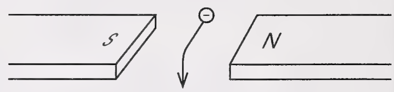
Use the following information to answer question 10.

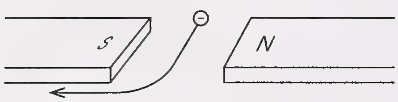
An electron moves through the magnetic field that exists between the ends of the magnets.

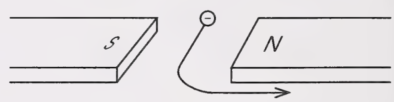


10. The diagram which best illustrates the path taken by the electron is

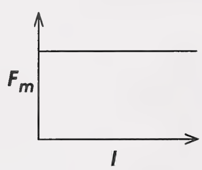
A.


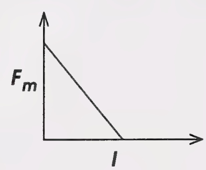
B.


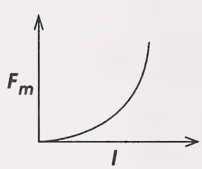
C.


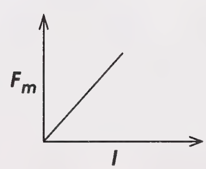
D.


11. A wire carrying a current is placed in an external magnetic field which runs perpendicular to the wire. Which of the following graphs best illustrates the relationship between the current carried by the wire and the force experienced by the wire?

A.


B.


C.


D.


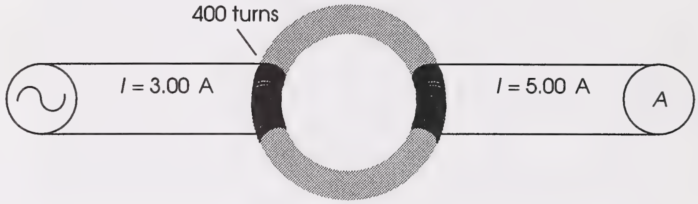
Part B: Numerical Response
5 Questions

Instructions

- Consider all numbers used in the questions to be the result of a measurement.
- Read each question carefully.

Use the following information to answer questions 12 and 13.

A simple transformer is constructed using coils of wire wrapped around an iron ring. One coil is attached to a source of AC voltage while the other is attached to an ammeter.

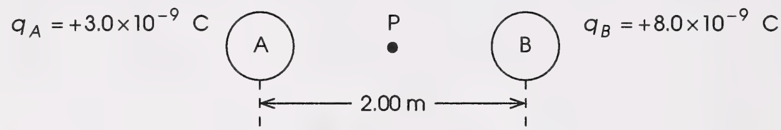


12. The number of turns in the secondary coil is N. The value of N is ________ .

13. A potential difference of 4.00 V is induced in the secondary coil. If the transformer is 97% efficient, the potential difference across the primary coil is b volts. The value of b is ________ . (Round and record your answer to three significant digits.)

Use the following information to answer question 14.

Two charges, A and B, are separated by 2.00 m as shown in the following diagram.



14. The magnitude of the electric field at a point midway between A and B is b N/C. The value of b is ______ . (Round and record your answer to two significant digits.)

---

15. The electrostatic force between two charges is 1.00×10^{2} N. If the value of each charge was doubled and the distance between them was doubled, the electrostatic force between the two charges would be $b \times 10^{w}$ N. The value of b is ______ . (Round and record your answer to three significant digits.)

16. A proton travelling at 2.0×10^{4} m/s enters perpendicular to a magnetic field of 6.50×10^{-2} T. The rate at which the proton will accelerate in the magnetic field is $b \times 10^{w}$ m/s^{2}. The value for w is ______ .

Part C: Written Response
1 Question

Instructions

- Consider all numbers used in the questions to be the result of a measurement.
- Read each question carefully.
- Write your answer as neatly as possible.

Use the following information to answer question 17.

A group of students wants to determine the average force of friction that acts on a particular toy car. The car they choose has no motor – it simply moves across the floor after being given a push. The force of friction will eventually cause the car to stop.

The students decide that, in addition to the car's mass, they also need to measure the car's initial speed and the corresponding distance that it travels before stopping. They do this for five trials. The data that they collected is shown on the following chart.

car's mass = 65.0 g

Speed (m/s)	0.60	0.80	1.00	1.20	1.40
Distance Travelled (m)	0.90	1.65	2.51	3.67	4.97

17. a. The students need an equation that relates the measured quantities of mass, initial speed, and distance travelled to the force of friction. Derive an equation for the force of friction using energy principles. This part is worth 1 mark.

    b. Plot a graph of distance versus speed with distance on the vertical axis. Be sure to use the standard graph paper with 1-cm squares. You will need at least ten squares on each axis. This part is worth $1\frac{1}{2}$ marks.

    c. Manipulate the data and replot the graph to produce a straight-line graph. Distance should be on the vertical axis. Be sure to use the standard graph paper with 1-cm squares. You will need at least ten squares on each axis. This part is worth 3 marks.

    d. Use the slope of your straight-line graph to calculate a value for the average force of friction. This part is worth $3\frac{1}{2}$ marks.

Check your answers by turning to the Appendix, Section 3: Activity 3.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

1. Describe the recommended attitude for approaching your diploma exam.

2. List three specific strategies that you will use to prepare for your exam.

Check your answers by turning to the Appendix, Section 3: Extra Help.

Enrichment

Do **one** of the following activities.

1. Ask Your Peers

   Take some time to ask your friends how they prepare for exams. Record the suggestions that they provide and ask how they usually score on the exams.

   Analyse your results for trends. Do your more successful friends have common methods of preparation?

2. Preparing for Recitals, Concerts, and Sports Events

   Many students have strategies for success that they apply when involved in events outside of school. Unfortunately, they don't realize that many of these same strategies can be applied to exam preparation. Try to think of one specific strategy from some other activity that could be applied to exam preparation.

Check your answers by turning to the Appendix, Section 3: Enrichment.

Conclusion

In this section you have been given both an approach and a number of strategies to help you prepare for your diploma exam. Many of these ideas will be helpful as you prepare for other exams in the future.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 3.

MODULE SUMMARY

This module has given you an example of how the nature of science influences the development of a scientific model. The scientific process requires that the only thing that is a fact in science is an observation or measurement. All models and theories are tentative; they can always be replaced by another model that provides a better explanation of the results. You've seen this point illustrated in the historical development of the models of the atom: the Thomson model was replaced by the Rutherford model, which was replaced by the Bohr model, which in turn was replaced by the quantum mechanical model. In time this model will eventually be improved or replaced as well.

This module also provided you with information about the Physics 30 diploma exam. Hopefully you found that the suggestions given in this module and the things that you've learned throughout the course will help you to be an effective problem solver both in your examination and in the other challenges that lie ahead in your life.

COURSE SURVEY FOR PHYSICS 30

Please evaluate this course and return this survey when you have completed your last module assignment. This is a course designed in a new distance-learning format, so we are interested in your responses. Your constructive comments will be greatly appreciated, as future course revisions can then incorporate any necessary improvements.

Name ______________________________ Course ______________________________

Address ______________________________ Age ❑ under 19 ❑ 19 to 40 ❑ over 40

______________________________ File No. ______________________________

______________________________ Date ______________________________

Design

1. This course contains a series of module booklets. Do you like the idea of separate booklets?

____

____

2. Have you ever enrolled in a correspondence course that arrived as one large volume?

❑ Yes ❑ No If yes, which style do you prefer?

____

____

3. The module booklets contained a variety of self-assessed activities. Did you find it helpful to be able to check your work and have immediate feedback?

❑ Yes ❑ No If yes, explain.

____

____

4. Were the questions and directions easy to understand?

❑ Yes ❑ No If no, explain.

____

____

5. Each section contains Follow-up Activities. Which type of follow-up activity did you choose?

   - ❑ mainly Extra Help
   - ❑ mainly Enrichment
   - ❑ a variety
   - ❑ none

   Did you find these activities beneficial?

   ❑ Yes ❑ No If no, explain.

   ____

   ____

6. Did you understand what was expected in the section assignments?

   ❑ Yes ❑ No If no, explain.

   ____

   ____

7. The course materials were designed to be completed by students working independently at a distance. Were you always aware of what you had to do?

   ❑ Yes ❑ No If no, provide details.

   ____

   ____

8. Suggestions for audiocassette and videocassette activities may have been included in the course. Did you make use of these media options?

   ❑ Yes ❑ No Comment on the lines below.

   ____

   ____

Course Content

1. Was enough detailed information provided to help you learn the expected skills and ojectives?

   ❑ Yes ❑ No Comment on the lines below.

   ____

   ____

2. Did you find the work load reasonable?

❑ Yes ❑ No If no, explain.

____

____

3. Did you have any difficulty with the reading level?

❑ Yes ❑ No Please comment.

____

____

4. How would you assess your general reading level?

❑ poor reader ❑ average reader ❑ good reader

5. Was the material presented clearly and with sufficient depth?

❑ Yes ❑ No If no, explain.

____

____

General

1. What did you like least about the course?

____

____

2. What did you like most about the course?

____

____

Additional Comments

____

____

____

Only students enrolled with the Alberta Distance Learning Centre need to complete the remaining questions.

1. Did you contact the Alberta Distance Learning Centre for help or information while doing your course?

   ❑ Yes ❑ No If yes, approximately how many times? ______

   Did you find the staff helpful?

   ❑ Yes ❑ No If no, explain.

2. Were you able to fax any of your assignment response pages?

   ❑ Yes ❑ No If yes, comment on the value of being able to do this.

3. If you were mailing your assignment response pages, how long was it taking for their return?

4. Was the feedback you received from your correspondence teacher helpful?

   ❑ Yes ❑ No Please comment.

Thanks for taking the time to complete this survey. Your feedback is important to us. Please return this survey with your last module assignment.

Instructional Design and Development
Alberta Distance Learning Centre
Box 4000
Barrhead, Alberta
T0G 2P0

Appendix

Glossary
Suggested Answers
Pull-out Page
Physics 30 Data Sheets

Glossary

absorption spectrum: a spectrum that occurs when light has certain wavelengths absorbed as it is passing through matter, resulting in a collection of dark lines

ballast: a device that stabilizes the current supplied to a fluorescent light bulb

bright line spectrum: another name for an emission spectrum

dark line spectrum: another name for an absorption spectrum

diffraction grating: a piece of glass or plastic etched with thousands of parallel lines that help produce an interference pattern

emission spectrum: a set of wavelengths emitted by an excited gas

energy band: an essentially continuous band produced by the blending of energy levels from many atoms in a solid

excited state: one of the allowed energy levels in an atom that is above the ground state

fluorescence: the process of absorbing one photon or particle and releasing a photon of lesser energy

forbidden gap: the region between allowed energy bands in a solid

gas discharge tube: a device that passes a high-voltage current through a gas at low pressure

ground state: the lowest allowed energy level in an atom

postulate: an essential starting idea that must be assumed to be true

quantum mechanics: a highly abstract, mathematical model of the atom based on the wave properties of matter

quantum number: the number of each of the allowed orbits; $n = 1, 2, 3, 4 \ldots$

spectra: the plural of spectrum

spectroscope: a device that enables the study of a spectrum

spectrum: a collection of wavelengths from the electromagnetic spectrum

stationary state: an allowed orbit in which an electron does not radiate energy

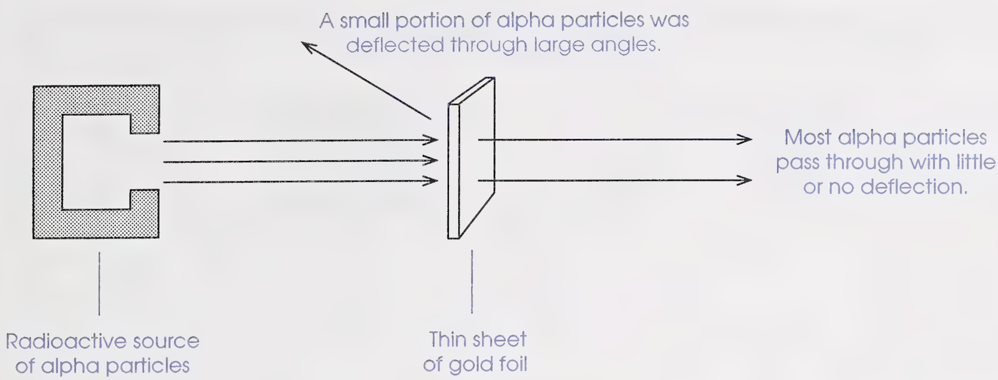
wave mechanics: another name for quantum mechanics

Suggested Answers

Section 1: Activity 1

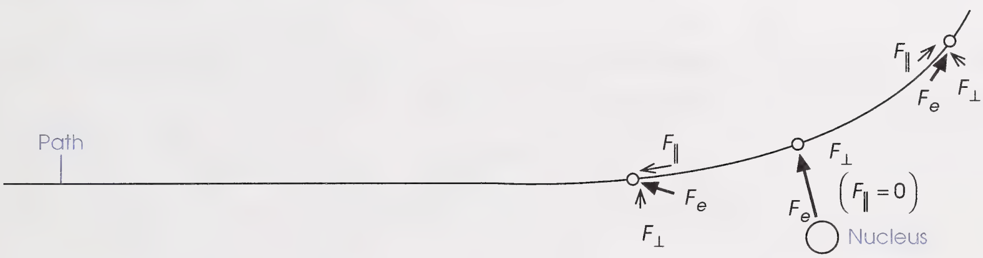
1. J.J. Thomson's model of the atom is often called the "raisin bun" or "plum pudding" model. This model describes the electrons being like little raisins spread throughout a larger, positive dough.

2.



3. The only way that a small positively charged alpha particle could be deflected through such large angles was if it struck something that was small, massive, and positively charged. Rutherford suggested that all the positive charge of an atom, as well as most of the mass, was concentrated in a massive central core called the nucleus.

4. The repelling force is labelled F_e in the following diagram.



5. This question is answered on the previous diagram.

6. The parallel component of the force changes the speed of the alpha particle by first decelerating it and then accelerating it.

7. The perpendicular component of the force changes the direction of the alpha particle.

8. Rutherford estimated that the largest possible radius for a gold nucleus was 3×10^{-14} m.

9. a. According to classical electromagnetic theory, the electron orbiting the nucleus should continually emit radiation since it is an accelerating charge. It follows that this would require a loss of energy from the atom, so the electron should have a deteriorating orbit that changes the frequency of the radiation emitted. Eventually the electron would crash into the nucleus.

   b. Electrons in stable atoms do not normally emit any radiation and, since they are stable, do not collide with the nucleus.

10. The electric potential energy will be very nearly zero when the two charges are separated by a distance (r) that is extremely large.

As r approaches infinity, E_p approaches zero, since they are inversely related.

$$E_p = \frac{kq_1q_2}{r}$$

11. $$\sum E_{before} = \sum E_{after}$$
$$E_p + E_k = E_p{}' + E_k{}'$$
$$0 + \frac{1}{2}mv^2 = \frac{kq_1q_2}{r} + 0$$
$$r = \frac{2kq_1q_2}{mv^2}$$
$$= \frac{2\left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(3.20\times10^{-19}\ \text{C}\right)\left(1.26\times10^{-17}\ \text{C}\right)}{\left(6.65\times10^{-27}\ \text{kg}\right)\left(2.0\times10^{7}\ \text{m/s}\right)^2}$$
$$= 2.7\times10^{-14}\ \text{m}$$

12. An alpha particle is a helium nucleus which consists of two neutrons and two protons. The protons each contribute $+1.60\times10^{-19}$ C of charge to give a total of $+3.20\times10^{-19}$ C.

13. The periodic table shows that gold has an atomic number of 79. This means that a neutral gold atom has 79 protons and 79 electrons. The protons each contribute 1.60×10^{-19} C of charge to give the gold nucleus a total charge of 1.264×10^{-17} C.

14. $r_{volleyball} = 10\ \text{cm}$

$r_{model} = ?$

$$\frac{r_{nucleus}}{r_{atom}} = \frac{1}{10\,000}$$

$$\frac{r_{nucleus}}{r_{atom}} = \frac{r_{volleyball}}{r_{model}}$$
$$\frac{1}{10\,000} = \frac{10\ \text{cm}}{r_{model}}$$
$$r_{model} = (10\ \text{cm})(10\,000)$$
$$= 100\,000\ \text{cm}$$
$$= 1000\ \text{m}$$
$$= 1.0\ \text{km}$$

The answer indicates that if someone was holding a volleyball in the middle of a large field, an electron would be a smaller object orbiting 1.0 km away. This suggests that the interior of most atoms is mostly empty space.

Section 1: Activity 2

1. An emission spectrum is a set of light wavelengths emitted by an excited gas.

2. The gas discharge tube uses a high-voltage electric current to excite the atoms of a gas under low pressure. The gas is sealed within a glass tube that has electrodes at both ends.

3. A spectroscope is a device that uses either a prism or a diffraction grating to separate a ray of light into its component wavelengths. A quantitative spectroscope permits the measurement of these wavelengths.

4. The images are different because there are different sources for each of the types of light. Car headlights use a hot tungsten filament, so they produce a continuous spectrum. The street lamps use sodium vapour, so they produce an emission spectrum of a few bright lines.

5. Textbook question 10:

$$\text{number of lines} = 2.50 \times 10^{3}$$
$$\text{distance containing the number of lines} = 1\ \text{cm (exact)}$$
$$\text{distance between adjacent lines} = d = ?$$

$$\begin{aligned} d &= \frac{\text{distance containing the number of lines}}{\text{number of lines}} \\ &= \frac{1\ \text{cm}}{2.5 \times 10^{3}} \\ &= 4.00 \times 10^{-4}\ \text{cm} \\ &= 4.00 \times 10^{-6}\ \text{m} \end{aligned}$$

Textbook question 11:

$$d = 4.00 \times 10^{-4}\ \text{cm} = 4.00 \times 10^{-6}\ \text{m}$$
$$x = 16.5\ \text{cm} = 0.165\ \text{m}$$
$$\ell = 1.00\ \text{m}$$
$$n = 1$$

$$\begin{aligned} \theta &= \tan^{-1}\left(\frac{x}{\ell}\right) \\ &= \tan^{-1}\left(\frac{0.165\ \text{m}}{1.00\ \text{m}}\right) \\ &= 9.369^\circ \end{aligned}$$

$$\begin{aligned} \lambda &= \frac{d(\sin\theta)}{n} \\ &= \frac{(4.00 \times 10^{-6}\ \text{m})(\sin 9.369^\circ)}{1} \\ &= 6.51 \times 10^{-7}\ \text{m} \end{aligned}$$

Textbook question 12:

$$\begin{aligned} d &= \frac{1\ \text{cm}}{12\,000\ \text{lines}} \\ &= 8.\overline{3} \times 10^{-5}\ \text{cm} \\ &= 8.\overline{3} \times 10^{-7}\ \text{m} \end{aligned}$$
$$n = 1$$

Red:

$$\lambda = 632\ \text{nm} = 6.32 \times 10^{-7}\ \text{m}$$
$$\theta = ?$$

$$\lambda = \frac{d(\sin\theta)}{n}$$
$$\sin\theta = \frac{n\lambda}{d}$$
$$\begin{aligned} \theta &= \sin^{-1}\left(\frac{n\lambda}{d}\right) \\ &= \sin^{-1}\left(\frac{1(6.32 \times 10^{-7}\ \text{m})}{(8.\overline{3} \times 10^{-7}\ \text{m})}\right) \\ &= 49.3^\circ \end{aligned}$$

Blue:

$$\lambda = 421\ \text{nm} = 4.21 \times 10^{-7}\ \text{m}$$
$$\theta = ?$$

$$\lambda = \frac{d(\sin\theta)}{n}$$
$$\begin{aligned} \theta &= \sin^{-1}\left(\frac{n\lambda}{d}\right) \\ &= \sin^{-1}\left(\frac{1(4.21 \times 10^{-7})}{(8.\overline{3} \times 10^{-7}\ \text{m})}\right) \\ &= 30.3^\circ \end{aligned}$$

6. Since the wavelength of red is longest and blue is shortest, the wavelengths of the lines are as follows:

$\lambda_{red} = 6.60 \times 10^{-7}$ m $\lambda_{green} = 5.50 \times 10^{-7}$ m $\lambda_{blue} = 4.84 \times 10^{-7}$ m

7. You would have to memorize the order of the colours in the spectrum from longest wavelength to smallest. (Some students use the name Roy G Biv to remember the proper order.)

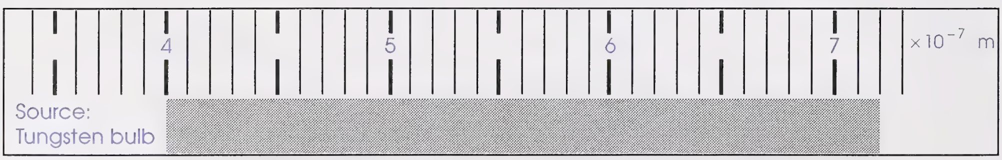
8. An absorption spectrum occurs when light has certain wavelengths removed as it is passing through cool gases, resulting in a collection of dark lines.

9. The lines that a sample will absorb in its absorption spectrum are the same lines that it will emit in its emission spectrum.

10. Spectroscopy can be used to identify the composition of the sun and other stars by studying the absorption spectra of their light. This is how Fraunhofer's lines were used to determine the composition of the cloud of gases surrounding the sun. Spectroscopy can also be used to determine the composition of metals by analysing spectra of tiny vapourized samples.

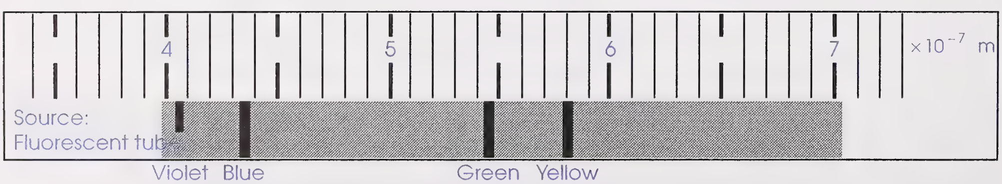
11. Gerhard Herzberg was a Canadian scientist who won the 1971 Nobel Prize in chemistry for his work in molecular spectroscopy.

12. The following answer shows that a continuous spectrum was produced from 4.0×10^{-7} m (violet) to 7.0×10^{-7} m (red). Your answer may differ slightly depending on the sensitivity of your eyes.



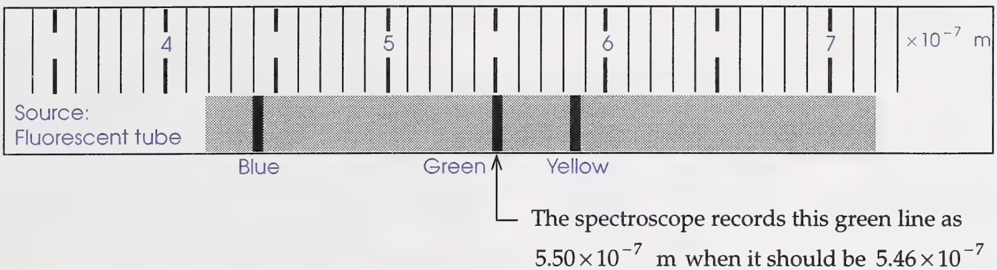
13. The bulb produced a continuous spectrum. This means that the source of the light is a hot solid.

14. The following sample answer shows **both** a continuous spectrum and a bright line spectrum of four lines. Your answer may vary depending on the sensitivity of your eyes (most people can only see three lines) and the calibration of the spectroscope.

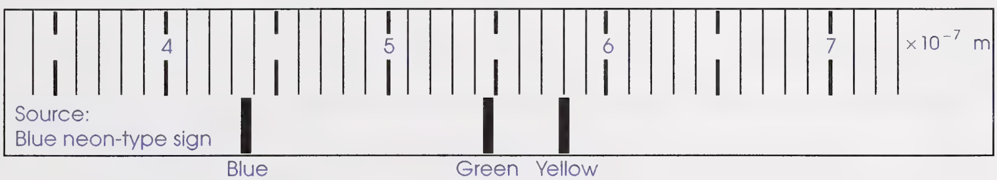


15. The fluorescent light fixture produced both a continuous spectrum and a bright line emission spectrum. The sources of the light must be both a hot solid and an excited gas.

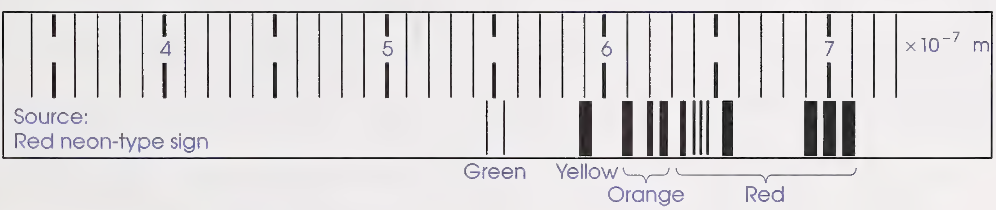
16. The answers to this question will vary depending on the individual spectroscope you are using. For example, if your spectroscope gave the following pattern for the fluorescent light, you'd know that your values for wavelength will be slightly larger than they really are.



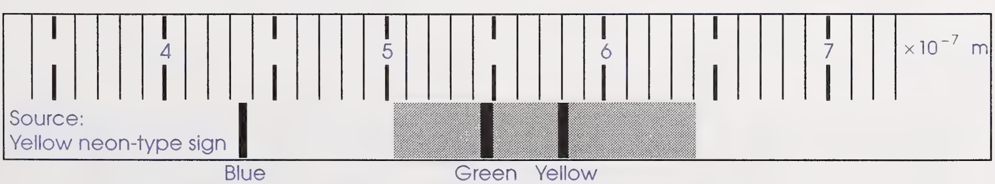
17. The following data represents samples taken from a number of the sources listed. These samples were collected from a spectroscope with no calibration errors. A concise description of the likely source is included.



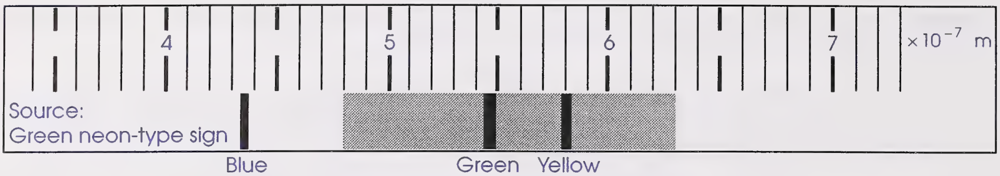
This sign likely contains mercury vapour.



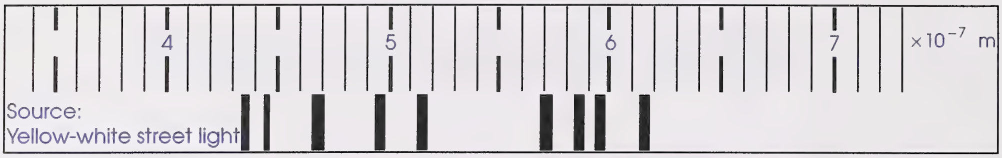
This sign likely contains neon gas.



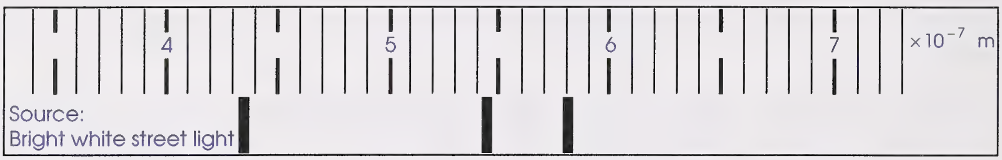
This sign contains mercury vapour and a hot solid that emits part of a continuous spectrum. (The coating on the inside of the glass tube creates the continuous spectrum. You'll learn more about this in the next section.)



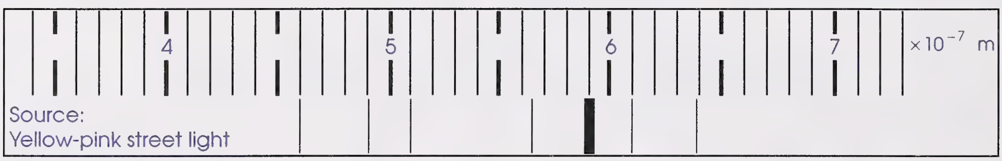
This sign likely contains mercury vapour and a hot solid that emits part of a continuous spectrum.



The light from this street light does not match any of the samples presented.



The light from this street light indicates that the lamp contains mercury vapour.



The light from this street light indicates that the lamp contains low-pressure sodium.

18. The following sample data was based on the sample data shown in the previous questions. Your answers may vary depending on the sources that you used.

Source	Element Likely to Be Present
blue neon-type sign	mercury vapour
red neon-type sign	neon gas
yellow neon-type sign	mercury vapour (plus unknown hot solid)
green neon-type sign	mercury vapour (plus unknown hot solid)
yellow-white street light	unknown from the five sources given*
bright-white street light	mercury vapour
yellow-pink street light	low-pressure sodium

*Note that most city streets are lit by street lights that have the yellow-white light described in detail by the spectrum in the previous question. These street lights use high-pressure sodium vapour to create a much wider spectrum of light than what is produced by low-pressure sodium. This allows objects to retain a much truer colour than what is rendered by low-pressure street lights.

19. The most common element in neon-type signs is mercury vapour.

Section 1: Activity 3

1. Red line:

$n = 3$

$\lambda = ?$

Original equation:

$$\lambda = b\left(\frac{n^2}{n^2 - 2^2}\right)$$

$$= \left(3.6456 \times 10^{-7}\ \text{m}\right)\left(\frac{3^2}{3^2 - 2^2}\right)$$

$$= 3.6456 \times 10^{-7}\ \text{m}\left(\frac{9}{5}\right)$$

$$= 6.56 \times 10^{-7}\ \text{m}$$

Modern equation:

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

$$= \left(1.097 \times 10^7\ \text{m}^{-1}\right)\left(\frac{1}{2^2} - \frac{1}{3^2}\right)$$

$$= \left(1.097 \times 10^7\ \text{m}^{-1}\right)\left(\frac{1}{4} - \frac{1}{9}\right)$$

$$= \left(1.097 \times 10^7\ \text{m}^{-1}\right)\left(\frac{5}{36}\right)$$

$$\frac{1}{\lambda} = 1.5236 \times 10^6\ \text{m}^{-1}$$

$$\lambda = 6.56 \times 10^{-7}\ \text{m}$$

Note that your calculator may not automatically display your answer in scientific notation. In this case the first answer displayed would be 0.000 000 6. However, since you need an answer to three significant digits, you need to have the answer displayed in scientific notation. Consult the manual for your calculator if you are uncertain how to get your calculator to do this. If you use the rounded version of the Rydberg constant, $1.10 \times 10^7\ \text{m}^{-1}$, the modern equation would yield a value of $6.55 \times 10^{-7}\ \text{m}$.

2. Green line:
$n = 4$

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$
$$= \left(1.10\times10^7\ \text{m}^{-1}\right)\left(\frac{1}{2^2} - \frac{1}{4^2}\right)$$
$$= \left(1.10\times10^7\ \text{m}^{-1}\right)\left(\frac{1}{4} - \frac{1}{16}\right)$$
$$\frac{1}{\lambda} = 2.0625\times10^6\ \text{m}^{-1}$$
$$\lambda = 4.85\times10^{-7}\ \text{m}$$

Blue line:
$n = 5$

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$
$$= \left(1.10\times10^7\ \text{m}^{-1}\right)\left(\frac{1}{2^2} - \frac{1}{5^2}\right)$$
$$= \left(1.10\times10^7\ \text{m}^{-1}\right)\left(\frac{1}{4} - \frac{1}{25}\right)$$
$$\frac{1}{\lambda} = 2.31\times10^6\ \text{m}^{-1}$$
$$\lambda = 4.33\times10^{-7}\ \text{m}$$

Violet line:
$n = 6$

$$\frac{1}{\lambda} = R_H\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$
$$= \left(1.10\times10^7\ \text{m}^{-1}\right)\left(\frac{1}{2^2} - \frac{1}{6^2}\right)$$
$$= \left(1.10\times10^7\ \text{m}^{-1}\right)\left(\frac{1}{4} - \frac{1}{36}\right)$$
$$\frac{1}{\lambda} = 2.444\ 44\times10^6\ \text{m}^{-1}$$
$$\lambda = 4.09\times10^{-7}\ \text{m}$$

Note that the values calculated for the wavelengths are slightly smaller than the measured values due to the fact that the rounded version of the Rydberg constant was used.

3. According to the application of classical electromagnetic theory applied to Rutherford's model of the atom, all atoms should continually emit radiation of a decreasing frequency.

4. Atoms normally do not emit radiation. If atoms of a gas under low pressure are excited by an electric current, an emission spectrum will be produced.

5. Classical electromagnetic theory predicted that electrons orbiting the nucleus in the Rutherford atom will eventually lose enough energy that they will spiral in towards the nucleus.

6. Neils Bohr tried to unite Rutherford's nuclear model of the atom with Einstein's quantum theory of light. This was considered courageous because Einstein's theory was still not widely accepted.

7. The ground state is the lowest allowed energy level in an atom.

8. An excited state is an allowed energy level that is above the ground state in an atom.

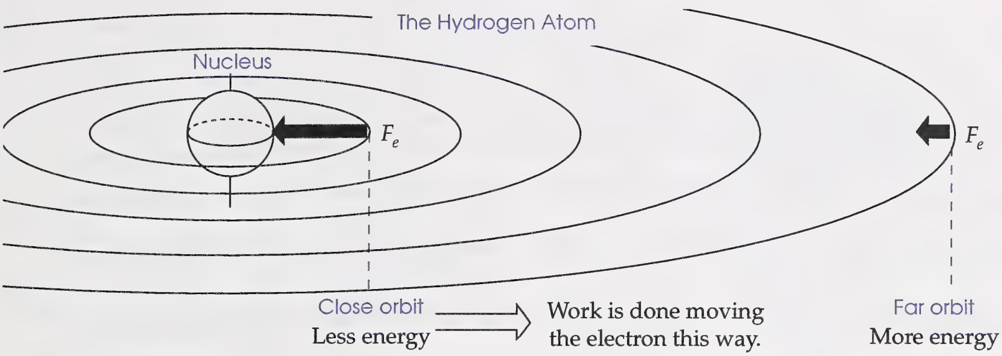
9. Energy levels further from the nucleus have more energy than the closer levels because work must be done against the Coulomb force to push the electron further away. This work increases the potential energy of the atom, resulting in a higher energy level.

10. When a hydrogen atom emits light, an electron is making a transition from a high energy level to a lower one. Therefore, by the law of conservation of energy, if the atom reduces its energy, the energy difference must take another form. The energy lost by the atom takes the form of a photon of emitted light. The wavelength of the light emitted corresponds to the energy of the photon according to Einstein's equation $E = \frac{hc}{\lambda}$.

11. The transition which involves the smallest change in energy is E_3 to E_2. This transition creates the photon with the longest wavelength because energy and wavelength are inversely related, as given by $E = \frac{hc}{\lambda}$.

12. The transition which produces the largest change in energy is E_6 to E_2. This transition creates a photon with the shortest wavelength because energy and wavelength are inversely related, as given by $E = \frac{hc}{\lambda}$.

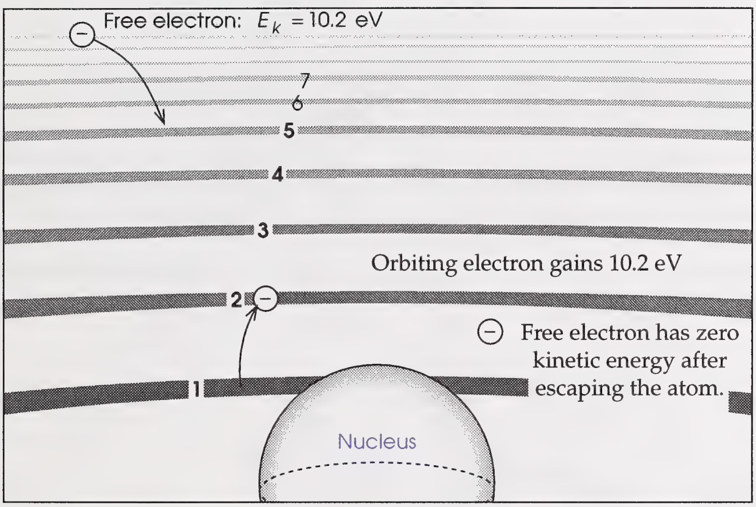
13.



14. This question is answered in the previous diagram.

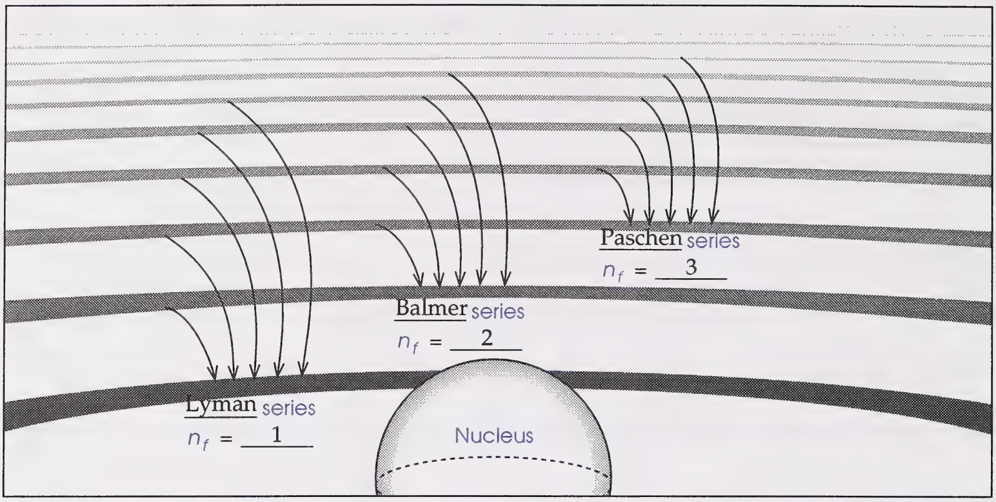
15. A hydrogen atom theoretically has an infinite number of energy levels.

16.



17. The Lyman series is in the ultraviolet part of the spectrum and the Paschen series is in the infrared part of the spectrum.

18.

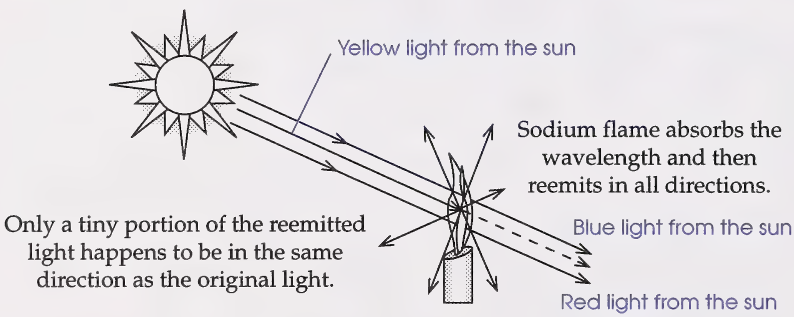


19. The Lyman series involves the largest possible energy transitions of all – from the excited states to the ground state. This high-energy transition should produce high-energy ultraviolet photons.

The Paschen series involves transitions to the third energy level, E_3. These transitions will involve smaller energy changes than the Balmer series does, so the photons emitted should have less energy than the visible wavelengths in the Balmer series. It follows that the Paschen series should involve infrared photons.

20. Every line in the hydrogen spectrum corresponds to an energy difference between two allowed energy levels within the hydrogen atom.

21.



22. The sodium flame does not actually remove the light, but rather it absorbs the light and then reemits it such that very little of the light is allowed to travel in the original direction.

Section 1: Activity 4

1.

$$F_e = F_c$$

Substitution:
$q = q$ proton $= q$ electron
r_n is the symbol for the nth radius

$$\frac{kq^2}{r_n^{\,2}} = \frac{mv^2}{r_n}$$

$$mvr_n = \frac{nh}{2\pi}$$

Bohr's third postulate

Rearrange.

$$v = \frac{nh}{2\pi m r_n}$$

Square both sides.

$$v^2 = \frac{n^2h^2}{4\pi^2 m^2 r_n^{\,2}}$$

Substitute.

$$\frac{kq^2}{r_n^{\,2}} = \frac{m}{r_n}\left(\frac{n^2h^2}{4\pi^2 m^2 r_n^{\,2}}\right)$$

Remove brackets and simplify.

$$\frac{kq^2}{\cancel{r_n}^{\cancel{2}}} = \frac{\cancel{m}n^2h^2}{r_n^{\cancel{3}}4\pi^2 m^{\cancel{2}}}$$

Rearrange.

$$r_n = \frac{n^2h^2}{4\pi^2 mkq^2}$$

Substitute values from Physics 30 data sheets.

$$r_n = \frac{n^2\left(6.63\times10^{-34}\ \text{J}\bullet\text{s}\right)^2}{4\pi^2\left(9.11\times10^{-31}\ \text{kg}\right)\left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(1.60\times10^{-19}\ \text{C}\right)^2}$$

Calculate the value of all the constants.

$$r_n = n^2\left(5.31\times10^{-11}\ \text{m}\right)$$

If $n = 1,\ r_n = r_1$.

$$r_1 = (1)^2\left(5.31\times10^{-11}\ \text{m}\right)$$

$$r_1 = 5.31\times10^{-11}\ \text{m}$$

Substitute.

$$r_n = n^2 r_1$$

2.

$r_1 = 5$ mm

$$\begin{aligned} r_2 &= 2^2\, r_1 \\ &= 4(5\ \text{mm}) \\ &= 20\ \text{mm} \end{aligned}$$

$$\begin{aligned} r_3 &= 3^2\, r_1 \\ &= 9(5\ \text{mm}) \\ &= 45\ \text{mm} \end{aligned}$$

$$\begin{aligned} r_4 &= 4^2\, r_1 \\ &= 16(5\ \text{mm}) \\ &= 80\ \text{mm} \end{aligned}$$

$$\begin{aligned} r_5 &= 5^2\, r_1 \\ &= 25(5\ \text{mm}) \\ &= 125\ \text{mm} \end{aligned}$$

3. $r_1 = 5$ mm
   $n = 10$
   $r_{10} = ?$

$$\begin{aligned} r_n &= n^2 r_1 \\ r_{10} &= 10^2\, r_1 \\ &= 100(5\ \text{mm}) \\ &= 500\ \text{mm} \end{aligned}$$

No, this radius would not fit on your page because it is half a metre from the nucleus.

4. Textbook question 1:

$$\begin{aligned} \frac{r_2}{r_1} &= \frac{2^2(r_1)}{1^2(r_1)} \\ &= \frac{4}{1} \\ &= 4 \end{aligned}$$

The second orbit has a radius four times larger than the first.

Textbook question 2:

$r_n = n^2 r_1$

$r_1 = 5.29 \times 10^{-11}$ m

$r_2 = ?$

$r_3 = ?$

$r_4 = ?$

Second orbit:

$$r_2 = (2)^2 r_1$$
$$= 4\left(5.29 \times 10^{-11}\text{ m}\right)$$
$$= 2.12 \times 10^{-10}\text{ m}$$

Third orbit:

$$r_3 = (3)^2 r_1$$
$$= 9\left(5.29 \times 10^{-11}\text{ m}\right)$$
$$= 4.76 \times 10^{-10}\text{ m}$$

Fourth orbit:

$$r_4 = (4)^2 r_1$$
$$= 16\left(5.29 \times 10^{-11}\text{ m}\right)$$
$$= 8.46 \times 10^{-10}\text{ m}$$

5.

Bohr's third postulate

$$mv_n r_n = \frac{nh}{2\pi}$$

Rearrange.

$$v_n = \frac{nh}{2\pi m r_n}$$

From the derivation of $r_n = n^2 r_1$

$$r_n = \frac{n^2 h^2}{4\pi^2 mkq^2}$$

Substitute.

$$v_n = \frac{nh}{2\pi m\left(\dfrac{n^2h^2}{4\pi^2 mkq^2}\right)}$$

Rearrange.

$$v_n = \frac{\cancel{n}\cancel{h}\,\overset{2}{\cancel{4}}\pi^{\cancel{2}}\cancel{m}kq^2}{\cancel{2}\cancel{\pi}\cancel{m}n^{\cancel{2}}h^{\cancel{2}}}$$

Simplify.

$$v_n = \left(\frac{2\pi kq^2}{h}\right)\frac{1}{n}$$

Substitute values from the Physics 30 data sheets.

$$v_n = \left(\frac{2\pi\left(8.99 \times 10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)\left(1.60 \times 10^{-19}\ \text{C}\right)^2}{6.63 \times 10^{-34}\ \text{J}\bullet\text{s}}\right)\frac{1}{n}$$

$$v_n = \frac{2.18 \times 10^6 \text{ m/s}}{n}$$

If $n = 1$, $v_n = v_1$.

$$v_1 = \frac{\left(2.18 \times 10^6 \text{ m/s}\right)}{1}$$

$$v_1 = 2.18 \times 10^6 \text{ m/s}$$

Substitute.

$$v_n = \frac{v_1}{n}$$

6. $v_n = \dfrac{v_1}{n}$

$v_1 = 2.18 \times 10^6$ m/s
$v_2 = ?$
$v_3 = ?$
$v_4 = ?$

Second orbit:

$$v_2 = \frac{v_1}{2} = \frac{2.18 \times 10^6 \text{ m/s}}{2} = 1.09 \times 10^6 \text{ m/s}$$

Third orbit:

$$v_3 = \frac{v_3}{3} = \frac{2.18 \times 10^6 \text{ m/s}}{3} = 7.27 \times 10^5 \text{ m/s}$$

Fourth orbit:

$$v_4 = \frac{v_4}{4} = \frac{2.18 \times 10^6 \text{ m/s}}{4} = 5.45 \times 10^5 \text{ m/s}$$

7.

$$E_n = E_k + E_p$$

Substitute.

$$E_n = \frac{1}{2}mv_n^2 + \frac{-kqq}{r_n}$$

From the derivation of $v_n = \frac{v_1}{n}$

$$v_n = \frac{2\pi kq^2}{hn}$$

Substitute.

From the derivation of $r_n = n^2 r_1$

$$r_n = \frac{n^2h^2}{4\pi^2 mkq^2}$$

Substitute.

$$E_n = \frac{1}{2}m\left(\frac{2\pi kq^2}{hn}\right)^2 + \frac{-kqq}{\left(\dfrac{n^2h^2}{4\pi^2 mkq^2}\right)}$$

Remove brackets.

$$E_n = \frac{\frac{1}{2}m4\pi^2k^2q^4}{h^2n^2} - \frac{kq^2\,4\pi^2mkq^2}{h^2n^2}$$

Simplify.

$$E_n = 2\left(\frac{\pi^2 mk^2 q^4}{h^2 n^2}\right) - 4\left(\frac{\pi^2 mk^2 q^4}{h^2 n^2}\right)$$

Combine terms.

$$E_n = \frac{-2\pi^2 mk^2 q^4}{h^2 n^2}$$

Isolate the constants from n^2.

$$E_n = -\left(\frac{2\pi^2 mk^2 q^4}{h^2}\right)\frac{1}{n^2}$$

Substitute values from the Physics 30 data sheets.

$$E_n = -\left(\frac{2\pi^2 \left(9.11\times10^{-31}\ \text{kg}\right)\left(8.99\times10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2\right)^2\left(1.60\times10^{-19}\ \text{C}\right)^4}{\left(6.63\times10^{-34}\ \text{J}\bullet\text{s}\right)^2}\right)\frac{1}{n^2}$$

$$E_n = \frac{-\left(2.17\times10^{-18}\ \text{J}\right)}{n^2}$$

$$E_n = \frac{-13.6\ \text{eV}}{n^2}$$

If $n=1,\ E_n = E_1$.

$$E_1 = \frac{-13.6\ \text{eV}}{1^2}$$

$$E_1 = -13.6\ \text{eV}$$

Substitute.

$$E_n = \frac{E_1}{n^2}$$

8. $E_n = \dfrac{-E_1}{n^2}$

$E_1 = -13.6 \text{ eV}$
$E_2 = ?$
$E_3 = ?$
$E_4 = ?$

Second orbit:

$$E_2 = \frac{-13.6 \text{ eV}}{2^2} = \frac{-13.6 \text{ eV}}{4} = -3.40 \text{ eV}$$

Third orbit:

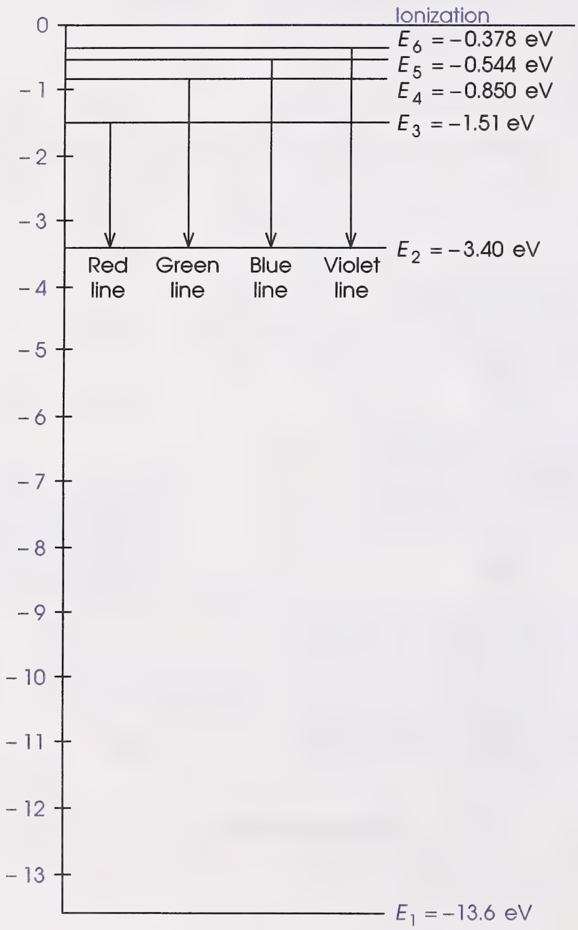
$$E_3 = \frac{-13.6 \text{ eV}}{3^2} = \frac{-13.6 \text{ eV}}{9} = -1.51 \text{ eV}$$

Fourth orbit:

$$E_4 = \frac{-13.6 \text{ eV}}{4^2} = \frac{-13.6 \text{ eV}}{16} = -0.850 \text{ eV}$$

9. a.

Energy-Level Diagram for Hydrogen



b. The calculations for the first four energy levels are shown in previous questions.

$$E_n = \frac{E_1}{n^2}$$

$E_1 = -13.6\ \text{eV}$
$E_2 = -3.40\ \text{eV}$
$E_3 = -1.51\ \text{eV}$
$E_4 = -0.850\ \text{eV}$

Fifth orbit:

$$E_5 = \frac{-13.6\ \text{eV}}{5^2} = \frac{-13.6\ \text{eV}}{25} = -0.544\ \text{eV}$$

Sixth orbit:

$$E_6 = \frac{-13.6\ \text{eV}}{6^2} = \frac{-13.6\ \text{eV}}{36} = -0.378\ \text{eV}$$

These six energy levels are shown on the previous diagram.

10. This question is answered in the previous diagram.

11. a. Red line: E_3 to E_2

$$\begin{aligned}\Delta E &= E_3 - E_2 \\ &= (-1.51\ \text{eV}) - (-3.40\ \text{eV}) \\ &= 1.89\ \text{eV} \\ &= 1.89\ \text{eV} \times \left[\frac{1.60 \times 10^{-19}\ \text{J}}{1\ \text{eV}}\right] \\ &= 3.02 \times 10^{-19}\ \text{J}\end{aligned}$$

b.

$$\begin{aligned}E_{light} &= \Delta E \\ \frac{hc}{\lambda} &= \Delta E \\ \lambda &= \frac{hc}{\Delta E} \\ &= \frac{(6.63 \times 10^{-34}\ \text{J} \bullet \text{s})(3.00 \times 10^{8}\ \text{m/s})}{3.02 \times 10^{-19}\ \text{J}} \\ &= 6.59 \times 10^{-7}\ \text{m}\end{aligned}$$

An answer of 6.58×10^{-7} m is also acceptable if an unrounded energy value is substituted.

12. Green line: E_4 to E_2

$$\begin{aligned}\Delta E &= E_4 - E_2 \\ &= (-0.850\ \text{eV}) - (-3.40\ \text{eV}) \\ &= 2.55\ \text{eV} \\ &= 2.55\ \text{eV} \times \left[\frac{1.60 \times 10^{-19}\ \text{J}}{1\ \text{eV}}\right] \\ &= 4.08 \times 10^{-19}\ \text{J}\end{aligned}$$

$$\begin{aligned}E_{light} &= \Delta E \\ \frac{hc}{\lambda} &= \Delta E \\ \lambda &= \frac{hc}{\Delta E} \\ &= \frac{(6.63 \times 10^{-34}\ \text{J} \bullet \text{s})(3.00 \times 10^{8}\ \text{m/s})}{4.08 \times 10^{-19}\ \text{J}} \\ &= 4.88 \times 10^{-7}\ \text{m}\end{aligned}$$

Blue line: E_5 to E_2

$$\begin{aligned}\Delta E &= E_5 - E_2\\ &= (-0.544\ \text{eV}) - (-3.40\ \text{eV})\\ &= 2.856\ \text{eV}\\ &= 2.856\ \text{eV} \times \left[\frac{1.60\times 10^{-19}\ \text{J}}{1\ \text{eV}}\right]\\ &= 4.57\times 10^{-19}\ \text{J}\end{aligned}$$

$$\begin{aligned}E_{light} &= \Delta E\\ \frac{hc}{\lambda} &= \Delta E\\ \lambda &= \frac{hc}{\Delta E}\\ &= \frac{(6.63\times 10^{-34}\ \text{J}\bullet\text{s})(3.00\times 10^{8}\ \text{m/s})}{4.57\times 10^{-19}\ \text{J}}\\ &= 4.35\times 10^{-7}\ \text{m}\end{aligned}$$

Violet line: E_6 to E_2

$$\begin{aligned}\Delta E &= E_6 - E_2\\ &= (-0.378\ \text{eV}) - (-3.40\ \text{eV})\\ &= 3.022\ \text{eV}\\ &= 3.022\ \text{eV} \times \left[\frac{1.60\times 10^{-19}\ \text{J}}{1\ \text{eV}}\right]\\ &= 4.84\times 10^{-19}\ \text{J}\end{aligned}$$

$$\begin{aligned}E_{light} &= \Delta E\\ \frac{hc}{\lambda} &= \Delta E\\ \lambda &= \frac{hc}{\Delta E}\\ &= \frac{(6.63\times 10^{-34}\ \text{J}\bullet\text{s})(3.00\times 10^{8}\ \text{m/s})}{4.84\times 10^{-19}\ \text{J}}\\ &= 4.11\times 10^{-7}\ \text{m}\end{aligned}$$

13. Differences are due to the fact that the initial energy values were rounded off earlier when the energy-level diagram was made.

14. The lines bunch up at the violet end of the spectrum because the energy levels themselves bunch up at the higher levels. For example, since E_6 and E_5 are so close, the wavelengths that correspond to a transition from these levels to E_2 are also close.

15. There are an infinite number of lines since there are an infinite number of levels.

16. The shortest possible wavelength occurs when the largest energy transition is made in the Balmer series. This would occur when an electron moved from the ionization level $(E_\infty = 0)$ to E_2.

E_∞ to E_2

$$\begin{aligned}\Delta E &= E_\infty - E_2\\ &= 0 - (-3.40\ \text{eV})\\ &= 3.40\ \text{eV} \times \left[\frac{1.60\times 10^{-19}\ \text{J}}{1\ \text{eV}}\right]\\ &= 5.44\times 10^{-19}\ \text{J}\end{aligned}$$

$$\begin{aligned}E_{light} &= \Delta E\\ \frac{hc}{\lambda} &= \Delta E\\ \lambda &= \frac{hc}{\Delta E}\\ \lambda &= \frac{(6.63\times 10^{-34}\ \text{J}\bullet\text{s})(3.00\times 10^{8}\ \text{m/s})}{5.44\times 10^{-19}\ \text{J}}\\ &= 3.66\times 10^{-7}\ \text{m}\end{aligned}$$

Section 1: Follow-up Activities

Extra Help

1. a. Electrons would have to be represented by objects that are two thousand times lighter than a pea and that could orbit around the pea. A tiny flea or dust mite are possibilities. Another would be tiny specks of dust that may be moving on air currents through the room.

   b. If tiny objects were to pass right through this room, how likely is it that one would pass within ten diameters of the pea? You can see that the chances of a close approach are very small because the room is mostly empty space.

   This is the conclusion that Rutherford came to. Since only one in eight thousand alpha particles are deflected straight back, the chances of an interaction with the nucleus must be very, very small because the atom is also mostly empty space.

2. a. All the lines in the visible spectrum of hydrogen involve an energy transition down to E_2.

   b. The red line is the first because it occurs due to the transition from E_3 to E_2. Since E_3 is the first energy level above E_2, the first line in the series is due to this transition.

   c. Red line: E_3 to E_2

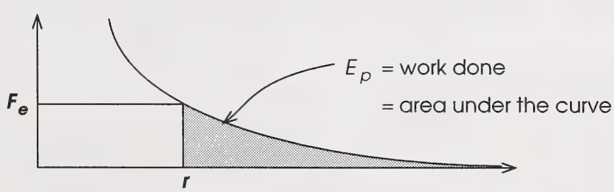
$$
\begin{aligned}
\Delta E &= E_3 - E_2 \\
&= (-1.51 \text{ eV}) - (-3.40 \text{ eV}) \\
&= 1.89 \text{ eV} \\
&= 1.89 \text{ eV} \times \left[\frac{1.60 \times 10^{-19} \text{ J}}{1 \text{ eV}}\right] \\
&= 3.02 \times 10^{-19} \text{ J}
\end{aligned}
$$

$$
\begin{aligned}
E_{light} &= \Delta E \\
\frac{hc}{\lambda} &= \Delta E \\
\lambda &= \frac{hc}{\Delta E} \\
&= \frac{(6.63 \times 10^{-34} \text{ J}\bullet\text{s})(3.00 \times 10^{8} \text{ m/s})}{3.02 \times 10^{-19} \text{ J}} \\
&= 6.59 \times 10^{-7} \text{ m}
\end{aligned}
$$

An answer of 6.58×10^{-7} m is also acceptable if an unrounded energy value is substituted.

Enrichment

1. a. Work can be calculated from the area under a force versus distance graph. Since the work is done from infinity to the distance r, the work done is the area under the curve from infinity to the distance r.



b. The shape of the area is not a simple shape like a rectangle or triangle. It is a curve because the force is always changing. If the space under the curve was divided up into tiny rectangles, the area under the curve could be found by summing the areas of all the rectangles, but there are an infinite number of them!

c. Here is one interpretation of the calculus notation:

$$\underbrace{\int_{\infty}^{r} F \bullet dr}_{} = \int_{\infty}^{r} \underbrace{\frac{kq_1q_2}{r^2}}_{} dr = \frac{-kq_1q_2}{r}$$

The function defining the curve is $\frac{kq_1q_2}{r^2}$. This determines the height for each of the tiny rectangles.

Find the sum of an infinite number of rectangular areas from infinity (∞) to the distance r. Each area is found by multiplying an exceptionally tiny width (dr) by the force at that point (F).

2. a. Planets move in elliptical orbits with the sun located at one focus. The speed of the planet increases as it moves closer to the sun and slows down as it moves away from the sun. If electrons are orbiting on a planetary model, they could do the same thing.

b. Equations describing circular motion would have to be substituted with ones describing elliptical motion. The speed of an electron was considered to be constant for a given orbit. This would also have to change. This would change the derivation of r_n, v_n, and E_n.

c. The force of repulsion between electrons would influence both the kinetic energy and potential energy of each electron. The derivation of E_n would change substantially because of the interactions among all the particles.

d. The conditions would be continually changing from one instant to the next, so time would need to become a variable introduced into all the equations. A statistical approach would be the only way to sort this out.

Section 2: Activity 1

1. Bohr's model had the following successes:

- calculating the lines in the emission spectrum for hydrogen
- calculating the ionization energy of hydrogen
- Energy levels for other elements were derived to match spectral data.
- Insight was gained into some of the chemical properties of the elements.

2. Bohr's model had the major shortcomings that his postulates could not be explained in terms of known physics. For example:

- Why was no radiation emitted from an orbiting electron?
- Why was angular momentum quantized?

Section 2: Activity 2

1. Circumference of orbit = a whole number of electron wavelengths — Condition for standing waves

   ↓ Substitute.

   $$2\pi r = n\lambda \qquad n = 1,\ 2,\ 3,\ \ldots$$

   $$\lambda = \frac{h}{mv}$$ → Substitute.

   $$2\pi r = n\left(\frac{h}{mv}\right)$$

   ↓ Rearrange.

   $$mvr = n\frac{h}{2\pi}$$

2. The derivation is not based on an unproven postulate. It is based on a physical description of the electron's behaviour.

3.

	Born/Heisenberg	Schrödinger
Assumptions	The electron behaves as a particle.	The electron behaves as a wave.
Mathematics	matrix computation	partial differential equations
Conclusions	The nucleus is surrounded by a cloud of electron matter waves.	The nucleus is surrounded by a cloud of electron matter waves.

4. The position of an electron can only be stated as a probability.

5. You are most likely to find an electron where the electron cloud is the most dense.

6. The wave mechanical model can be applied to describe the complex energy state of atoms with many electrons as well as molecules consisting of many atoms.

7. The wave mechanical model describes the electron as something that behaves like a wave sometimes and like a particle at other times. So you can't picture it as a hard little orbiting planet. There is no everyday large-scale object that exhibits wave/particle duality.

   The other difficulty is that electrons can't be represented by a definite orbit because their position is described in terms of probability. Figure 28-15 shows the probability of finding an electron in terms of a cloud of electron matter waves.

8. Wave mechanics has been used by chemists to understand existing molecules and to create new ones. Physicists used wave mechanics to develop a new source of light called a laser.

9. An energy level is a property of an individual atom. Electrons can exist only in sharply defined, discrete energy levels. An energy band results as the energy levels of many atoms in a solid blend together. This is shown in Figure 29-1(c) where the energy levels of many atoms can create broad bands. An energy band is a wider region of allowed energies.

10. The forbidden gap is the region between the allowed energy bands in a solid. No electrons can occupy this region.

Section 2: Activity 3

1. The vertical bars on the graph show an emission spectrum because only certain wavelengths of light are emitted. The lines match the four principal lines in the visible spectrum of mercury. The lines between 300 nm and 350 nm are not visible because they are in the ultraviolet part of the spectrum.

2. The continuous curving part of the graph shows the continuous spectrum of a hot solid. The phosphor crystals on the inside of the bulb are responsible for this light.

3. $\lambda = 254 \text{ nm}$

   $= 2.54 \times 10^{-7} \text{ m}$

$$E = \frac{hc}{\lambda}$$

$$= \frac{\left(6.63 \times 10^{-34} \text{ J}\bullet\text{s}\right)\left(3.00 \times 10^{8} \text{ m/s}\right)}{\left(2.54 \times 10^{-7} \text{ m}\right)}$$

$$= 7.831 \times 10^{-19} \text{ J}$$

$$= 7.831 \times 10^{-19} \text{ J}\left[\frac{1 \text{ eV}}{1.60 \times 10^{-19} \text{ J}}\right]$$

$$= 4.89 \text{ eV}$$

4. The energy state E_3 is the most likely candidate for the transition to the ground state because it is 4.86 eV above the ground state, which very nearly matches the energy of the ultraviolet photon.

5. The photon released by the phosphor crystal will have less than half of the energy of the incident ultraviolet photon. If the energy is less, the wavelength must be greater since wavelength is inversely related to photon energy.

6. The photon on the right attains more energy due to the greater energy difference between its starting point and end point. This means that the photon on the right will have a shorter wavelength.

7. The photon shown in the middle has an energy that is in between the energy of the other two. It follows that this photon should have a wavelength between the other two and it should be placed between the other two in the spectrum. This means that the photon could be orange or yellow.

8. a. If the maximum amount of energy is absorbed, the mercury atom will be raised to energy level E_6, where E_6 is 7.70 eV above the ground state.

b. By the law of conservation of energy, if the atom absorbs 7.70 eV of the initial 7.84 eV, the free electron must leave with the remaining energy, 0.14 eV.

c. $\Delta E = 7.70\ \text{eV}$

$$= 7.70\ \text{eV}\left[\frac{1.60\times10^{-19}\ \text{J}}{1\ \text{eV}}\right]$$

$$= 1.232\times10^{-18}\ \text{J}$$

$\lambda = ?$

$$E_{light} = \Delta E_{atom}$$

$$\frac{hc}{\lambda} = \Delta E$$

$$\lambda = \frac{hc}{\Delta E}$$

$$= \frac{(6.63\times10^{-34}\ \text{J}\bullet\text{s})(3.00\times10^{8}\ \text{m/s})}{(1.232\times10^{-18}\ \text{J})}$$

$$= 1.614\times10^{-7}\ \text{m}$$

$$= 1.61\times10^{-7}\ \text{m}$$

This wavelength corresponds to the ultraviolet part of the spectrum.

d. $E_{UV} = 1.232\times10^{-18}\ \text{J}$

$$E_{thermal} = 0.649(1.232\times10^{-18}\ \text{J})$$

$$= 8.00\times10^{-19}\ \text{J}$$

$$E_{visible} = 0.351(1.232\times10^{-18}\ \text{J})$$

$$= 4.324\times10^{-19}\ \text{J}$$

$\lambda = ?$

These calculations are based on the law of conservation of energy.

$$\underset{100\%}{E_{UV}} = \underset{64.9\%}{E_{thermal}} + \underset{35.1\%}{E_{visible}}$$

$$E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E}$$

$$= \frac{(6.63\times10^{-34}\ \text{J}\bullet\text{s})(3.00\times10^{8}\ \text{m/s})}{4.324\times10^{-19}\ \text{J}}$$

$$= 4.60\times10^{-7}\ \text{m}$$

This wavelength corresponds to the visible part of the spectrum in the blue/green region.

9. a. $E_6 = -2.68 \text{ eV}$

$E_4 = -4.95 \text{ eV}$

$E_{light} = ?$

$\lambda = ?$

$$\begin{aligned}\Delta E &= E_6 - E_4 \\ &= (-2.68 \text{ eV}) - (-4.95 \text{ eV}) \\ &= 2.27 \text{ eV} \\ &= 2.27 \text{ eV}\left[\frac{1.60 \times 10^{-19} \text{ J}}{1 \text{ eV}}\right] \\ &= 3.632 \times 10^{-19} \text{ J}\end{aligned}$$

$$\begin{aligned}E_{light} &= \Delta E \\ \frac{hc}{\lambda} &= \Delta E \\ \lambda &= \frac{hc}{\Delta E} \\ &= \frac{(6.63 \times 10^{-34} \text{ J} \bullet \text{s})(3.00 \times 10^{8} \text{ m/s})}{(3.632 \times 10^{-19} \text{ J})} \\ &= 5.48 \times 10^{-7} \text{ m}\end{aligned}$$

This wavelength corresponds to the visible part of the spectrum in the green region.

b. The wavelength of this photon corresponds very closely to the bright green line seen through the spectroscope while looking at the fluorescent lamp. This means that the bright green line in the emission spectrum of mercury is likely due to a transition from E_6 to E_4 within the mercury atom. The slight difference from the predicted value of 5.46×10^{-7} m can be attributed to the values of the constants, which have been rounded to three significant digits.

c. E_4 to E_1

$E_4 = -4.95 \text{ eV}$

$E_1 = -10.38 \text{ eV}$

$\lambda = ?$

$$\begin{aligned}\Delta E &= E_4 - E_1 \\ &= (-4.95 \text{ eV}) - (-10.38 \text{ eV}) \\ &= 5.43 \text{ eV} \\ &= 5.43 \text{ eV}\left[\frac{1.60 \times 10^{-19} \text{ J}}{1 \text{ eV}}\right] \\ &= 8.688 \times 10^{-19} \text{ J}\end{aligned}$$

$$\begin{aligned}E_{light} &= \Delta E \\ \frac{hc}{\lambda} &= \Delta E \\ \lambda &= \frac{hc}{\Delta E} \\ &= \frac{(6.63 \times 10^{-34} \text{ J} \bullet \text{s})(3.00 \times 10^{8} \text{ m/s})}{(8.688 \times 10^{-19} \text{ J})} \\ &= 2.289 \times 10^{-7} \text{ m} \\ &= 2.29 \times 10^{-7} \text{ m}\end{aligned}$$

d. $E_{UV} = 8.688 \times 10^{-19} \text{ J}$

$\lambda_{visible} = 5.90 \times 10^{-7} \text{ m}$

$E_{visible} = ?$

$E_{thermal} = ?$

$$\begin{aligned}E_{visible} &= \frac{hc}{\lambda} \\ &= \frac{(6.63 \times 10^{-34} \text{ J} \bullet \text{s})(3.00 \times 10^{8} \text{ m/s})}{(5.90 \times 10^{-7} \text{ m})} \\ &= 3.371 \times 10^{-19} \text{ J} \\ &= 3.37 \times 10^{-19} \text{ J}\end{aligned}$$

By law of conservation of energy:

$$E_{UV} = E_{visible} + E_{thermal}$$
$$\begin{aligned} E_{thermal} &= E_{UV} - E_{visible} \\ &= \left(8.688\times10^{-19}\ \text{J}\right)-\left(3.371\times10^{-19}\ \text{J}\right) \\ &= 5.317\times10^{-19}\ \text{J} \\ &= 5.32\times10^{-19}\ \text{J} \end{aligned}$$

10. a. E_6 to E_3

$E_6 = -2.68$ eV
$E_3 = -5.52$ eV
$\lambda = ?$

$$\begin{aligned} \Delta E &= E_6 - E_3 \\ &= (-2.68\ \text{eV})-(-5.52\ \text{eV}) \\ &= 2.84\ \text{eV} \\ &= 2.84\ \text{eV}\left[\frac{1.60\times10^{-19}\ \text{J}}{1\ \text{eV}}\right] \\ &= 4.544\times10^{-19}\ \text{J} \end{aligned}$$

$$\begin{aligned} E_{light} &= \Delta E \\ \frac{hc}{\lambda} &= \Delta E \\ \lambda &= \frac{hc}{\Delta E} \\ &= \frac{\left(6.63\times10^{-34}\ \text{J}\bullet\text{s}\right)\left(3.00\times10^{8}\ \text{m/s}\right)}{\left(4.544\times10^{-19}\ \text{J}\right)} \\ &= 4.377\times10^{-7}\ \text{m} \\ &= 4.38\times10^{-7}\ \text{m} \end{aligned}$$

This wavelength corresponds to the visible part of the spectrum in the blue region.

b. The wavelength of this photon corresponds very closely to the bright blue line seen through the spectroscope while looking at the fluorescent lamp. This means that the bright blue line in the emission spectrum of mercury is likely due to a transition from E_6 to E_3 within the mercury atom. The slight difference from the predicted value of 4.36×10^{-7} can be attributed to the values of the constants, which have been rounded to three significant digits.

c. E_3 to E_1

$E_3 = -5.52$ eV
$E_1 = -10.38$ eV
$\lambda = ?$

$$\begin{aligned} \Delta E &= E_3 - E_1 \\ &= (-5.52\ \text{eV})-(-10.38\ \text{eV}) \\ &= 4.86\ \text{eV} \\ &= 4.86\ \text{eV}\left[\frac{1.60\times10^{-19}\ \text{J}}{1\ \text{eV}}\right] \\ &= 7.776\times10^{-19}\ \text{J} \end{aligned}$$

$$\begin{aligned} E_{light} &= \Delta E \\ \frac{hc}{\lambda} &= \Delta E \\ \lambda &= \frac{hc}{\Delta E} \\ &= \frac{\left(6.63\times10^{-34}\ \text{J}\bullet\text{s}\right)\left(3.00\times10^{8}\ \text{m/s}\right)}{\left(7.776\times10^{-19}\ \text{J}\right)} \\ &= 2.558\times10^{-7}\ \text{m} \\ &= 2.56\times10^{-7}\ \text{m} \end{aligned}$$

d. $E_{UV} = 7.776 \times 10^{-19}\ \text{J}$

$E_{visible} = (0.399)(7.776 \times 10^{-19}\ \text{J})$

$= 3.103 \times 10^{-19}\ \text{J}$

$\lambda = ?$

$$E = \frac{hc}{\lambda}$$

$$\lambda = \frac{hc}{E}$$

$$= \frac{(6.63 \times 10^{-34}\ \text{J} \bullet \text{s})(3.00 \times 10^{8}\ \text{m/s})}{(3.103 \times 10^{-19}\ \text{J})}$$

$$= 6.41 \times 10^{-7}\ \text{m}$$

These calculations are based on the law of conservation of energy.

$$\underset{100\%}{E_{UV}} = \underset{60.1\%}{E_{thermal}} + \underset{39.9\%}{E_{visible}}$$

The phosphor coating will emit a photon from the visible region on the spectrum. This wavelength is from the red region of the spectrum.

11. The huge numbers of mercury vapour atoms are being bombarded by electrons with varying energies. The mercury will produce a variety of visible and ultraviolet photons that correspond to the energy transitions within the mercury atom. Some of the visible photons will penetrate the walls of the tube and form the bright lines seen in the spectroscope. In turn, the phosphor crystals will be bombarded by a variety of visible and ultraviolet photons from the mercury atoms. The ultraviolet photons will cause the phosphor crystals to emit a variety of visible photons through fluorescence. The net effect of photons reaching your eye from all regions of the visible spectrum is interpreted to be white light.

12. In a ship the ballast is any heavy load used to improve the stability of the ship. Special ballast tanks are often filled with water to make sure that the ship is perfectly balanced and that the ship has enough inertia that it won't rock back and forth so much in rough seas.

    The ballast in a fluorescent fixture stabilizes the current and keeps it from rocking back and forth.

13. Power drawn by the ballast:

    $I = 0.833\ \text{A}$
    $V = 120\ \text{V}$

    $P = IV$

    $= (0.833\ \text{A})(120\ \text{V})$

    $= 100\ \text{W}$

    Power supplied to the fluorescent tubes:

    $I = 0.425\ \text{A}$
    $V = 191\ \text{V}$

    $P = IV$

    $= (0.425\ \text{A})(191\ \text{V})$

    $= 81.2\ \text{W}$

    The ballast appears to be 81.2% efficient.

14 a. $N_p = 100$ turns

$I_p = 0.833$ A

$I_s = 0.425$ A

$N_s = ?$

$$\frac{N_p}{N_s} = \frac{I_s}{I_p}$$

$$N_s = \frac{N_p I_p}{I_s} = \frac{(100 \text{ turns})(0.833 \text{ A})}{0.425 \text{ A}} = 196 \text{ turns}$$

b. $N_p = 100$ turns

$V_p = 120$ V

$V_s = 191$ V

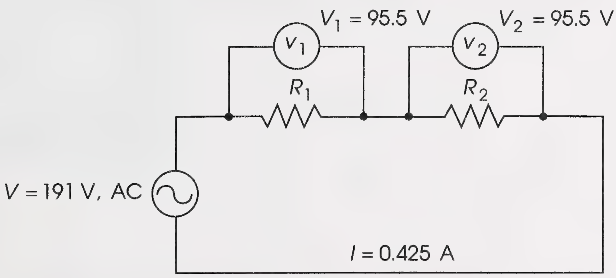
$N_s = ?$

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

$$N_s = \frac{N_p V_s}{V_p} = \frac{(100 \text{ turns})(191 \text{ V})}{120 \text{ V}} = 159 \text{ turns}$$

c. The transformer equation is based on the ideal transformer that is 100% efficient. The ballast is only 81.2% efficient as a transformer and this accounts for the discrepancy.

15. a.



b. This question is answered in the previous diagram.

c. $V_1 = 95.5$ V

$I_1 = 0.425$ A

$R_1 = ?$

$V_2 = 95.5$ V

$I_2 = 0.425$ A

$R_2 = ?$

Note that since the tubes are connected in series, the same current runs through each tube. Since the tubes are acting like identical resistors, they will have the same effective resistance and only one calculation is necessary.

$$V = IR$$

$$R = \frac{V}{I} = \frac{95.5 \text{ V}}{0.425 \text{ A}} = 225\ \Omega$$

16. a. A cool white fluorescent tube is about 21% efficient at creating light energy.

b. $t = 1.00\ \text{s}$

$V = 95.5\ \text{V}$

$I = 0.425\ \text{A}$

$E = ?$

$$P = IV$$

$$\frac{E}{t} = IV$$

$$\begin{aligned} E &= IVt \\ &= (0.425\ \text{A})(95.5\ \text{V})(1.00\ \text{s}) \\ &= 40.59\ \text{J} \\ &= 40.6\ \text{J} \end{aligned}$$

c. $E_{electric} = 40.59\ \text{J}$

$$\begin{aligned} E_{light} &= 0.21(40.59\ \text{J}) \\ &= 8.524\ \text{J} \\ &= 8.5\ \text{J} \end{aligned}$$

$$\begin{aligned} E_{thermal} &= 0.79(40.59\ \text{J}) \\ &= 32.07\ \text{J} \\ &= 32\ \text{J} \end{aligned}$$

These calculations are based on the law of conservation of energy.

$$\underset{\substack{\uparrow \\ 100\%}}{E_{electric}} = \underset{\substack{\uparrow \\ 21\%}}{E_{light}} + \underset{\substack{\uparrow \\ 79\%}}{E_{thermal}}$$

Section 2: Follow-up Activities

Extra Help

	Rutherford Model	Bohr Model	Quantum Mechanical Model
Identify the originator(s) of this model.	Ernest Rutherford	Neils Bohr	Erwin Schrödinger, Max Born, and Werner Heisenberg
When was this model first proposed?	1911	1913	1926 (Schrödinger) 1925 (Born and Heisenberg)
What ideas or experiments are the basis of this model?	Rutherford's experiments of scattering alpha particles from gold foil	Rutherford's model and Einstein's quantum theory of light; Bohr used these ideas to form his three postulates.	Bohr's model for hydrogen and de Broglie's matter wave interpretation of the electron; mathematical modelling
How does this model describe electrons?	Electrons are tiny particles that orbit the nucleus like planets orbiting the sun.	Electrons are tiny particles that orbit the nucleus like planets orbiting the sun.	Electrons are matter waves that surround the nucleus in the form of electron clouds.

	Rutherford Model	Bohr Model	Quantum Mechanical Model
How are electrons arranged in this model?	Each electron has its own orbit.	Electrons can only be found in the allowed energy levels.	The location of an electron cannot be stated precisely – only the probability of finding the electron in a particular location can be stated.
What kind of spectra are predicted by this model?	All atoms would continuously emit radiation of ever decreasing frequency. (This is not observed.)	Atoms emit or absorb light when their electrons make transitions between allowed energy levels. Each transition corresponds to one particular line in the spectrum.	This model predicts everything that the Bohr model does and it also predicts the brightness and splitting of spectral lines.
Which atom(s) can be described by this model?	Rutherford intended this model to apply to all atoms.	only hydrogen	all atoms and hydrogen

Enrichment

1. The detailed answer to this question will vary depending on the particular resource materials that you chose. The following answers summarize the important points that should be common to all answers.

   a. A metastable energy state is an excited energy state within some atoms in which the electrons can remain for a relatively long time, a few seconds to a few hours, before the transition is finally made to a lower energy state. By comparison, in the typical energy states of most atoms, the electron remains for a very short period of time – about 10^{-8} s.

   b. Phosphorescent materials are made up of atoms that have metastable energy states. Visible light photons can excite these atoms to metastable energy states, which will then take from a few seconds to a few hours to make a transition and emit a photon. Even a small sample will contain a huge number of these atoms, so the result is that the whole sample releases visible photons for a long time after it is initially excited.

2. a. Textbook question 6:

   The laser light is coherent and restricted to a very small beam. This makes the laser light more intense.

   Textbook question 7:

   The acronym stands for Microwave Amplification by Stimulated Emission of Radiation.

   Textbook question 8:

   As described in the answer to question 6, laser light is so coherent and directional that the beam remains relatively concentrated and intense even over great distances. This can be used to create images during laser light shows.

b. Textbook question 20:

$$\lambda = 10\,600 \text{ nm}$$
$$= 10\,600 \times 10^{-9} \text{ m}$$
$$= 1.0600 \times 10^{-5} \text{ m}$$
$$c = 3.00 \times 10^{8} \text{ m/s}$$
$$h = 6.63 \times 10^{-34} \text{ J} \bullet \text{s}$$
$$E = ?$$

$$E = \frac{hc}{\lambda}$$
$$= \frac{\left(6.63 \times 10^{-34} \text{ J} \bullet \text{s}\right)\left(3.00 \times 10^{8} \text{ m/s}\right)}{1.0600 \times 10^{-5} \text{ m}}$$
$$= 1.876 \times 10^{-20} \text{ J} \times \left[\frac{1 \text{ eV}}{1.60 \times 10^{-19} \text{ J}}\right]$$
$$= 0.117 \text{ eV}$$

Section 3: Activity 1

1. a. Mike should focus his energy on improving his personal best jump of 1.91 m. He should start training and preparing to make this goal a reality.

   b. No, the presence of the other competitor should not affect the approach that Mike takes. Mike is focusing on what he has to do, not on what the other competitor has to do.

   c. Mike should be pleased with his performance since he improved his personal best jump.

2. Answers to this question will vary but the idea here is that you should focus on trying to improve your personal best performance.

3. One of the best approaches is to start about three to four weeks before the exam by making a daily routine and weekly schedule for yourself. Many students mark the date of the exam on a calendar and then work backward from that date and pencil in a reasonable study schedule.

4. The diploma exam allows only a hand-held calculator, the Physics 30 Data Booklet, and assorted other materials such as a pencil, an eraser, and a clear plastic ruler and a protractor. Since you are not supposed to use a textbook or your notebook you should practise exam writing without them. The exam also has a time limit. You'll learn more about this later, but you should always work on your practice exam problems in a reasonable amount of time.

5. If an athlete began to think that everything was going to go wrong and dedicated lots of energy to worrying about the competition, negative results could be the outcome. Some athletes call this effect being psyched out.

6. When you think about writing the exam, try to develop a mental image of yourself calmly and confidently working through the questions. You know that some questions will be challenging, but you've been working on Physics 30 for a long time and you're ready.

Section 3: Activity 2

1. Approximately 30% of the exam will involve applying familiar concepts to new situations. You have been practising doing this throughout the course.

2. The first reason why this would not be a good idea is that recalling facts and explanations makes up only 10% of the exam. The second reason is that you are provided with the Physics 30 Data Booklet, so all the physical constants and equations are already provided for reference while writing the exam.

3. A calculator will likely not be needed for about half of the questions on the exam.

4. The written-response questions will likely require the most thoughtful and creative answers.

5. Once again, the overall goals of Physics 30 are to learn the big interconnecting ideas, to develop the skills of science, and to apply these things to applications in society and technology. Some of the concepts that you've learned in Physics 30 are quite sophisticated, so it was important to use equipment, collect data, make graphs, and solve problems to try to see the idea from as many angles as possible. Once you really understand the concept, you can apply it to new situations and begin to see how it connects to other ideas. The two charts shown really stress the point that it is vital that you're well-grounded in the major concepts of Physics 30.

6. This strategy won't work on a diploma exam because the answers are completely randomized. There is no point in wasting energy looking for patterns in the sequence of answers with As, Bs, Cs, and Ds because no such pattern exists.

7. Experience indicates that this method often results in annoying little errors that give wrong answers. Forgetting to change units or to include a constant frequently happens when this is done. The best technique is the one that you've been encouraged to use throughout the course: jot down the data, state the equation(s), rearrange algebraically, substitute in the data, and then solve.

8. All three types of questions require you to carefully read the question and determine what the question is asking.

Section 3: Activity 3

1. The answer is **D**, as shown by the following unit analysis.

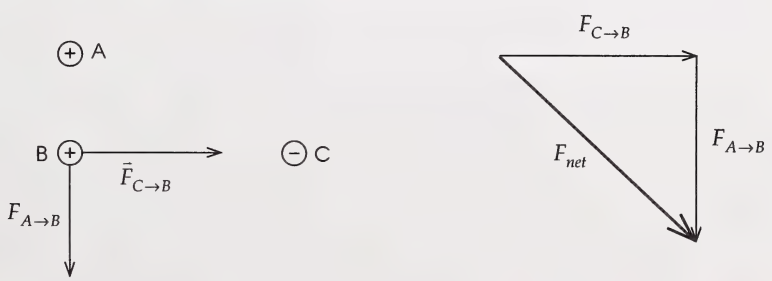
$$\mathrm{N \bullet s}$$
$$\left(\mathrm{kg \bullet m/s^2}\right)\mathrm{\bullet s}$$
$$\mathrm{kg \bullet m/s}$$

Another approach is to realize that $\mathrm{N \bullet s}$ is an impulse unit which is equal to a momentum unit.

2. The answer is **B** since the two objects touch.

3. The answer is **A** since electric forces can also repel.

4. The answer is **C**, as shown by the following vector analysis.



5. The answer is **A** because the negative charge on the balloon causes the electrons within the electroscope to be repelled to the leaves. This makes the leaves diverge further.

6. The best answer is **C**. The law of conservation of charge indicates that the total charge should be $+3q$. Since both objects are identical, they each get half of this total charge.

7. The best answer is **B** because the electron will move horizontally with uniform motion and vertically upward with accelerated motion due to the upward electric force. The result of both of these motions is a parabola tilting upward.

8. The best answer is **C** because resistors in parallel will have the same potential difference across them.

9. The best answer is **C** because of the right-hand rule for moving positive charges.

10. The best answer is **A** because of the left-hand rule for the force acting on a negative charge moving perpendicular to a magnetic field.

11. The best answer is **D** because in the equation $F_m = BI\ell$, the variables F_m and I are directly related to each other.

12. $I_p = 3.00\text{ A}$
$I_s = 5.00\text{ A}$
$N_p = 400\text{ turns}$
$N_s = ?$

$$\frac{N_p}{N_s} = \frac{I_s}{I_p}$$

$$N_s = \frac{N_p I_p}{I_s} = \frac{(400\text{ turns})(3.00\text{ A})}{(5.00\text{ A})} = 240\text{ turns}$$

The answer is 240.

13. $V_s = 4.00\text{ V}$
$V_p = ?$
$I_p = 3.00\text{ A}$
$I_s = 5.00\text{ A}$

$$\frac{P_s}{P_p} = 0.97$$

$$\frac{I_s V_s}{I_p V_p} = 0.97$$

$$V_p = \frac{I_s V_s}{I_p(0.97)} = \frac{(5.00\text{ A})(4.00\text{ V})}{(3.00\text{ A})(0.97)} = 6.87\text{ V}$$

The answer is 6.87.

14. $q_A = 3.0 \times 10^{-9}$ C
$r_A = 1.0$ m
$\left|\vec{E}_A\right| = ?$

$$\left|\vec{E}_A\right| = \frac{kq_A}{(r_A)^2}$$
$$= \frac{\left(8.99 \times 10^9 \text{ N} \bullet \text{m}^2/\text{C}^2\right)\left(3.0 \times 10^{-9} \text{ C}\right)}{(1.0 \text{ m})^2}$$
$$= 27.0 \text{ N/C}$$
$$\vec{E}_A = 27.0 \text{ N/C, right}$$

$q_B = 8.0 \times 10^{-9}$ C
$r_B = 1.0$ m
$\left|\vec{E}_B\right| = ?$

$$\left|\vec{E}_B\right| = \frac{kq_B}{(r_B)^2}$$
$$= \frac{\left(8.99 \times 10^9 \text{ N} \bullet \text{m}^2/\text{C}^2\right)\left(8.0 \times 10^{-9} \text{ C}\right)}{(1.0 \text{ m})^2}$$
$$= 71.9 \text{ N/C}$$
$$\vec{E}_B = 71.9 \text{ N/C, left}$$

$$\vec{E}_{net} = 44.9 \text{ N/C, left}$$
$$= 45 \text{ N/C, left}$$

The answer is 45.

15. Initial Conditions:

$$F_e = \frac{kq_1q_2}{r^2}$$
$$= 1.00 \times 10^2 \text{ N}$$

Final Conditions:

$$F_e' = \frac{kq_1'q_2'}{(r')^2}$$
$$= \frac{k2q_1 2q_2}{(2r)^2}$$
$$= \frac{\cancel{4}kq_1q_2}{\cancel{4}r^2}$$
$$= 1.00 \times 10^2 \text{ N}$$

The answer is 1.00.

16. $m = 1.67 \times 10^{-27}$ kg
$q = 1.60 \times 10^{-19}$ C
$v = 2.0 \times 10^4$ m/s
$B_\perp = 6.50 \times 10^{-2}$ T
$a = ?$

$$F_c = F_m$$
$$ma_c = qvB_\perp$$
$$a_c = \frac{qvB_\perp}{m}$$
$$= \frac{\left(1.60 \times 10^{-19} \text{ C}\right)\left(2.0 \times 10^4 \text{ m/s}\right)\left(6.50 \times 10^{-2} \text{ T}\right)}{1.67 \times 10^{-27} \text{ kg}}$$
$$= 1.25 \times 10^{11} \text{ m/s}^2$$

The answer is 11.

17. a. $\sum E_{before} = \sum E_{after}$

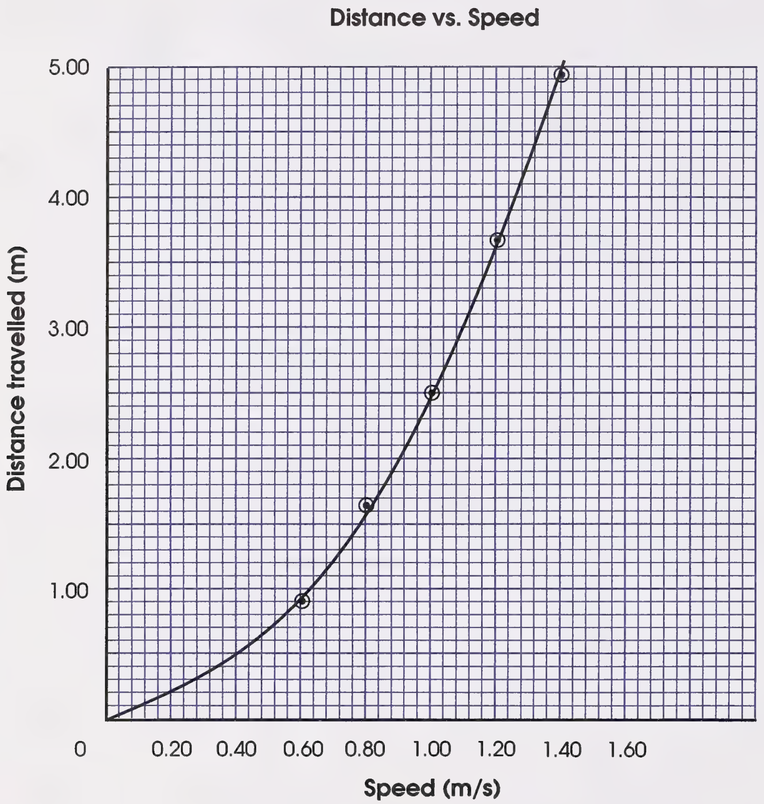
$$E_p + E_k = E_p{}' + E_k{}' + W'$$

$$0 + \frac{1}{2}mv^2 = 0 + 0 + F_f d$$

$$F_f = \frac{\frac{1}{2}mv^2}{d}$$

This part is worth 1 mark. Each line in the solution is worth $\frac{1}{4}$ mark if it is correctly communicated as shown.

b.

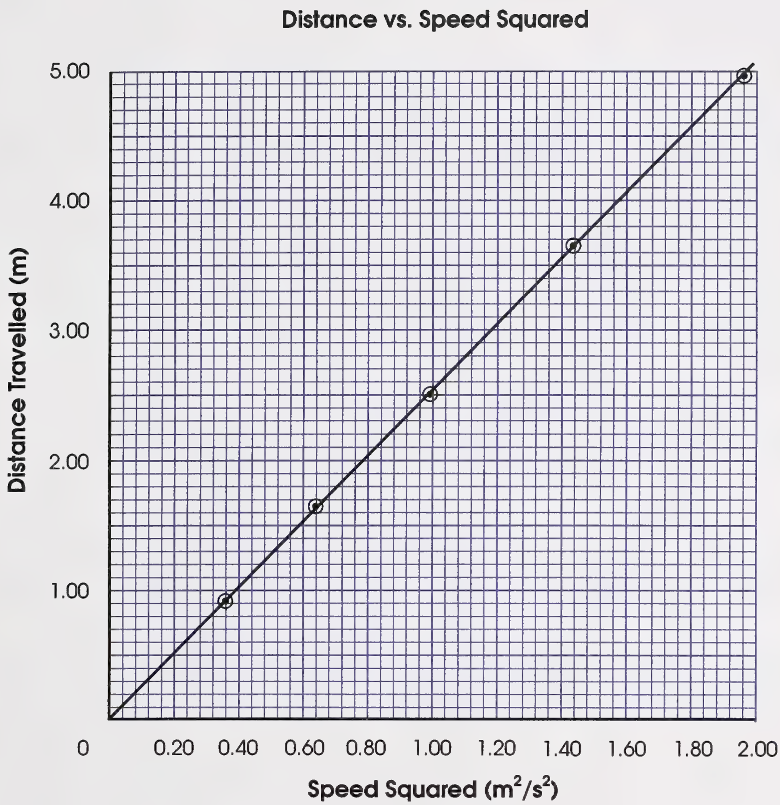


This part of the question is worth $1\frac{1}{2}$ marks. Correctly titling, labelling, and scaling the axis is worth $\frac{1}{2}$ mark. Plotting the points properly and drawing the best fit line (a curve) is worth 1 mark.

c. Calculate v^2 values.

Speed (m/s)	0.60	0.80	1.00	1.20	1.40
Distance Travelled (m)	0.90	1.65	2.51	3.67	4.97
Speed Squared (m^2/s^2)	0.36	0.64	1.00	1.44	1.96

This part of the question is worth 3 marks. Setting up this data chart to clearly display the values for distance and speed squared is worth 1 mark.



This graph is worth 2 marks. Correctly labelling the axis is worth a $\frac{1}{2}$ mark. Correctly scaling the axis is worth a half mark. Correctly plotting the points is worth a half mark. Correctly drawing the best fit straight line through the origin is worth a half mark.

d. $$\begin{aligned} \text{slope} &= \frac{\text{rise}}{\text{run}} \\ &= \frac{d}{v^2} \\ &= \frac{4.00\ \text{m} - 0\ \text{m}}{1.58\ \text{m}^2/\text{s}^2 - 0\ \text{m}^2/\text{s}^2} \\ &= 2.53\ \text{s}^2/\text{m} \end{aligned}$$

This part of the question is worth $3\frac{1}{2}$ marks.

Correctly calculating the slope is worth $\frac{1}{2}$ mark.
Properly communicating a correct solution for the force of friction is worth 3 marks.

$$F_f d = \frac{1}{2} m v^2 \qquad \text{From part a.}$$

By inspection:

$$\begin{array}{cccc} d = & \left(\dfrac{\frac{1}{2}m}{F_f}\right) & v^2 & \text{zero} \\ \downarrow & \downarrow & \downarrow & \downarrow \\ y = & m & x + & b \end{array}$$

$$\frac{\frac{1}{2}m}{F_f} = \text{slope}$$

$$\begin{aligned} F_f &= \frac{\frac{1}{2}m}{\text{slope}} \\ &= \frac{\frac{1}{2}(0.065\ \text{kg})}{2.53\ \text{s}^2/\text{m}} \\ &= 0.013\ \text{kg} \bullet \text{m/s}^2 \\ &= 1.3 \times 10^{-2}\ \text{N} \end{aligned}$$

Section 3: Follow-up Activities

Extra Help

1. The recommended attitude is one centered on confidence and positive thinking. Your goal should be to do your personal best on the exam and you should decide now that you will be responsible for the outcome.

2. The kind of confidence that was described in the first question is best created by careful and thorough preparation. You could have chosen any of the strategies from the following list:

   - Be active when you study.
   - Anticipate likely questions and try to answer them.
   - Work within your attention span when you study.
   - Stay healthy.
   - Practice writing exams under exam conditions.
   - Use the strategies for each of the types of questions when you write an exam.

Enrichment

1. The results for this activity will vary depending on what your friends say. However, you should notice that your more successful friends will employ more of the strategies listed in this section than those who are less successful.

2. The answers to this question will vary depending on your own interests. You may mention some of the things that have been mentioned in this module. You may also come up with some new insights. One example would be the special diet that athletes use to prepare for big events. A good exam preparation diet would include foods from the four food groups in the Canada Food Guide. Many people like to eat a little extra fruit the day of an exam because of the gentle boost in energy from the natural sugars. You may want to find out if you are allowed to take a piece of fruit with you into the exam as an energy booster. Just make sure that you can eat it quietly.

Section 1: Activity 2 Investigation: Spectral Analysis of Lighting

4 5 6 7 $\times 10^{-7}$ m

Source:

4 5 6 7 $\times 10^{-7}$ m

Source:

4 5 6 7 $\times 10^{-7}$ m

Source:

4 5 6 7 $\times 10^{-7}$ m

Source:

4 5 6 7 $\times 10^{-7}$ m

Source:

4 5 6 7 $\times 10^{-7}$ m

Source:

4 5 6 7 $\times 10^{-7}$ m

Source:

4 5 6 7 $\times 10^{-7}$ m

Source:

PHYSICS 30
DATA SHEETS

CONSTANTS

GRAVITY, ELECTRICITY, AND MAGNETISM

Acceleration Due to Gravity or Gravitational Field Near Earth	g or $a_g = 9.81\ \text{m/s}^2$ or $9.81\ \text{N/kg}$
Gravitational Constant	$G = 6.67 \times 10^{-11}\ \text{N}\bullet\text{m}^2/\text{kg}^2$
Mass of Earth	$M_e = 5.98 \times 10^{24}\ \text{kg}$
Radius of Earth	$R_e = 6.37 \times 10^{6}\ \text{m}$
Coulomb's Law Constant	$k = 8.99 \times 10^{9}\ \text{N}\bullet\text{m}^2/\text{C}^2$
Electron Volt	$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$
Elementary Charge	$e = 1.60 \times 10^{-19}\ \text{C}$
Index of Refraction of Air	$n = 1.00$
Speed of Light in Vacuum	$c = 3.00 \times 10^{8}\ \text{m/s}$

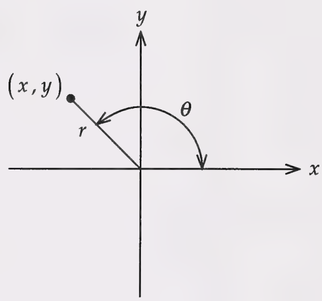
ATOMIC PHYSICS

Energy of an Electron in the 1st Bohr Orbit of Hydrogen	$E_1 = -2.18 \times 10^{-18}\ \text{J}$ or $-13.6\ \text{eV}$
Planck's Constant	$h = 6.63 \times 10^{-34}\ \text{J}\bullet\text{s}$
Radius of 1st Bohr Orbit of Hydrogen	$r_1 = 5.29 \times 10^{-11}\ \text{m}$
Rydberg's Constant for Hydrogen	$R_H = 1.10 \times 10^{7}\ /\text{m}$

PARTICLES

	Rest Mass	Charge
Alpha Particle	$m_\alpha = 6.65 \times 10^{-27}$ kg	α^{2+}
Electron	$m_e = 9.11 \times 10^{-31}$ kg	e^-
Neutron	$m_n = 1.67 \times 10^{-27}$ kg	n^0
Proton	$m_p = 1.67 \times 10^{-27}$ kg	p^+

TRIGONOMETRY AND VECTORS



$$\sin\,\theta = \frac{\textit{opposite}}{\textit{hypotenuse}} \text{ or } \sin\,\theta = \frac{y}{r}$$

$$\cos\,\theta = \frac{\textit{adjacent}}{\textit{hypotenuse}} \text{ or } \cos\,\theta = \frac{x}{r}$$

$$\tan\,\theta = \frac{\textit{opposite}}{\textit{adjacent}} \text{ or } \tan\,\theta = \frac{y}{x}$$

For any Vector $\vec{R}$

$$R = \sqrt{R_x{}^2 + R_y{}^2}$$

$$R_x = R\cos\,\theta$$

$$R_y = R\sin\,\theta$$

$$\tan\,\theta = \frac{R_y}{R_x}$$

$$\frac{a}{\sin\,A} = \frac{b}{\sin\,B} = \frac{c}{\sin\,C}$$

$$c^2 = a^2 + b^2 - 2ab\cos\,C$$

VALUES OF TRIGONOMETRIC FUNCTIONS

Angle	Sin	Cos	Tan	Angle	Sin	Cos	Tan
1°	0.0175	0.9998	0.0175	**46°**	0.7193	0.6947	1.0355
2°	0.0349	0.9994	0.0349	**47°**	0.7314	0.6820	1.0724
3°	0.0523	0.9986	0.0524	**48°**	0.7431	0.6691	1.1106
4°	0.0698	0.9976	0.0699	**49°**	0.7547	0.6561	1.1504
5°	0.0872	0.9962	0.0875	**50°**	0.7660	0.6428	1.1918
6°	0.1045	0.9945	0.1051	**51°**	0.7771	0.6293	1.2349
7°	0.1219	0.9925	0.1228	**52°**	0.7880	0.6157	1.2799
8°	0.1392	0.9903	0.1405	**53°**	0.7986	0.6018	1.3270
9°	0.1564	0.9877	0.1584	**54°**	0.8090	0.5878	1.3764
10°	0.1736	0.9848	0.1763	**55°**	0.8192	0.5736	1.4281
11°	0.1908	0.9816	0.1944	**56°**	0.8290	0.5592	1.4826
12°	0.2079	0.9781	0.2126	**57°**	0.8387	0.5446	1.5399
13°	0.2250	0.9744	0.2309	**58°**	0.8480	0.5299	1.6003
14°	0.2419	0.9703	0.2493	**59°**	0.8572	0.5150	1.6643
15°	0.2588	0.9659	0.2679	**60°**	0.8660	0.5000	1.7321
16°	0.2756	0.9613	0.2867	**61°**	0.8746	0.4848	1.8040
17°	0.2924	0.9563	0.3057	**62°**	0.8829	0.4695	1.8807
18°	0.3090	0.9511	0.3249	**63°**	0.8910	0.4540	1.9626
19°	0.3256	0.9455	0.3443	**64°**	0.8988	0.4384	2.0503
20°	0.3420	0.9397	0.3640	**65°**	0.9063	0.4226	2.1445
21°	0.3584	0.9336	0.3839	**66°**	0.9135	0.4067	2.2460
22°	0.3746	0.9272	0.4040	**67°**	0.9205	0.3907	2.3559
23°	0.3907	0.9205	0.4245	**68°**	0.9272	0.3746	2.4751
24°	0.4067	0.9135	0.4452	**69°**	0.9336	0.3584	2.6051
25°	0.4226	0.9063	0.4663	**70°**	0.9397	0.3420	2.7475
26°	0.4384	0.8988	0.4877	**71°**	0.9455	0.3256	2.9042
27°	0.4540	0.8910	0.5095	**72°**	0.9511	0.3090	3.0777
28°	0.4695	0.8829	0.5317	**73°**	0.9563	0.2924	3.2709
29°	0.4848	0.8746	0.5543	**74°**	0.9613	0.2756	3.4874
30°	0.5000	0.8660	0.5774	**75°**	0.9659	0.2588	3.7321
31°	0.5150	0.8572	0.6009	**76°**	0.9703	0.2419	4.0108
32°	0.5299	0.8480	0.6249	**77°**	0.9744	0.2250	4.3315
33°	0.5446	0.8387	0.6494	**78°**	0.9781	0.2079	4.7046
34°	0.5592	0.8290	0.6745	**79°**	0.9816	0.1908	5.1446
35°	0.5736	0.8192	0.7002	**80°**	0.9848	0.1736	5.6713
36°	0.5878	0.8090	0.7265	**81°**	0.9877	0.1564	6.3138
37°	0.6018	0.7986	0.7536	**82°**	0.9903	0.1392	7.1154
38°	0.6157	0.7880	0.7813	**83°**	0.9925	0.1219	8.1443
39°	0.6293	0.7771	0.8098	**84°**	0.9945	0.1045	9.5144
40°	0.6428	0.7660	0.8391	**85°**	0.9962	0.0872	11.4301
41°	0.6561	0.7547	0.8693	**86°**	0.9976	0.0698	14.3007
42°	0.6691	0.7431	0.9004	**87°**	0.9986	0.0523	19.0811
43°	0.6820	0.7314	0.9325	**88°**	0.9994	0.0349	28.6363
44°	0.6947	0.7193	0.9657	**89°**	0.9998	0.0175	57.2900
45°	0.7071	0.7071	1.0000	**90°**	1.0000	0.0000	Undefined

EQUATIONS

Kinematics

$$\vec{v}_{ave} = \frac{\vec{d}}{t}$$

$$\vec{d} = \left(\frac{\vec{v}_f + \vec{v}_i}{2}\right)t$$

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t}$$

$$v_f^2 = v_i^2 + 2ad$$

$$\vec{d} = \vec{v}_i t + \frac{1}{2}\vec{a}t^2$$

Dynamics

$$\vec{F} = m\vec{a}$$

$$F_g = \frac{Gm_1 m_2}{r^2}$$

$$\vec{F}t = m\Delta\vec{v}$$

$$g = \frac{Gm_1}{r^2}$$

$$\vec{F}_g = m\vec{g}$$

$$F_c = \frac{mv^2}{r}$$

$$F_f = \mu F_N$$

$$F_c = \frac{4\pi^2 mr}{T^2}$$

$$\vec{F}_s = -k\vec{x}$$

Momentum and Energy

$$\vec{p} = m\vec{v}$$

$$E_k = \frac{1}{2}mv^2$$

$$W = Fd$$

$$E_p = mgh$$

$$W = Fd\cos\theta$$

$$E_p = \frac{1}{2}kx^2$$

$$P = \frac{W}{t} = \frac{\Delta E}{t}$$

Waves and Light

$$T = 2\pi\sqrt{\frac{m}{k}}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$$

$$T = 2\pi\sqrt{\frac{l}{g}}$$

$$\lambda = \frac{xd}{nl}$$

$$T = \frac{1}{f}$$

$$\lambda = \frac{d\sin\theta}{n}$$

$$v = f\lambda$$

$$m = \frac{h_i}{h_0} = \frac{-d_i}{d_0}$$

$$\frac{\lambda_1}{2} = l;\ \frac{\lambda_1}{4} = l$$

$$\frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_i}$$

EQUATIONS

Electricity and Magnetism

$$F_e = \frac{kq_1q_2}{r^2}$$

$$\left|\vec{E}\right| = \frac{kq_1}{r^2}$$

$$\vec{E} = \frac{\vec{F}_e}{q}$$

$$\left|\vec{E}\right| = \frac{V}{d}$$

$$V = \frac{\Delta E}{q}$$

$$R = R_1 + R_2 + R_3$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$V = IR$$

$$P = IV$$

$$I = \frac{q}{t}$$

$$F_m = IlB_\perp$$

$$F_m = qvB_\perp$$

$$V = B_\perp lv$$

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p}$$

$$V_{eff} = 0.707\ V_{max}$$

$$I_{eff} = 0.707\ I_{max}$$

Atomic Physics

$$hf = E_{k_{max}} + W$$

$$W = hf_0$$

$$E_{k_{max}} = qV_{stop}$$

$$E = hf = \frac{hc}{\lambda}$$

$$\frac{1}{\lambda} = R_H\left(\frac{1}{n_f^{\,2}} - \frac{1}{n_i^{\,2}}\right)$$

$$E_n = \frac{1}{n^2}E_1$$

$$r_n = n^2 r_1$$

Relativity and Quantum Physics

$$E = mc^2$$

$$p = \frac{h}{\lambda}$$

$$p = \frac{hf}{c};\ E = pc$$

Periodic Chart of the Elements

Key

ATOMIC NUMBER → 1 H ← SYMBOL OF THE ELEMENT

2.1 ← ELECTRONEGATIVITY

NAME OF THE ELEMENT → hydrogen

ATOMIC MASS → 1.01

BASED ON $^{12}_{6}C$

( ) INDICATES MASS OF THE MOST STABLE ISOTOPE

Note: The Legend at the right denotes the physical state of the elements at 101 kPa and 298 K (25°C)

Legend

SOLID

LIQUID

GAS

IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA or 0
1 H 2.1 hydrogen 1.01																	2 He - helium 4.00
3 Li 1.0 lithium 6.94	4 Be 1.5 beryllium 9.01											5 B 2.0 boron 10.81	6 C 2.5 carbon 12.01	7 N 3.0 nitrogen 14.01	8 O 3.5 oxygen 16.00	9 F 4.0 fluorine 19.00	10 Ne - neon 20.17
11 Na 0.9 sodium 22.99	12 Mg 1.2 magnesium 24.31											13 Al 1.5 aluminum 26.98	14 Si 1.8 silicon 28.09	15 P 2.1 phosphorus 30.97	16 S 2.5 sulphur 32.06	17 Cl 3.0 chlorine 35.45	18 Ar - argon 39.95
19 K 0.8 potassium 39.10	20 Ca 1.0 calcium 40.08	21 Sc 1.3 scandium 44.96	22 Ti 1.5 titanium 47.90	23 V 1.6 vanadium 50.94	24 Cr 1.6 chromium 52.00	25 Mn 1.5 manganese 54.94	26 Fe 1.8 iron 55.85	27 Co 1.8 cobalt 58.93	28 Ni 1.8 nickel 58.71	29 Cu 1.9 copper 63.55	30 Zn 1.6 zinc 65.38	31 Ga 1.6 gallium 69.74	32 Ge 1.8 germanium 72.59	33 As 2.0 arsenic 74.92	34 Se 2.4 selenium 78.96	35 Br 2.8 bromine 79.90	36 Kr - krypton 83.80
37 Rb 0.8 rubidium 85.47	38 Sr 1.0 strontium 87.62	39 Y 1.3 yttrium 88.91	40 Zr 1.4 zirconium 91.22	41 Nb 1.6 niobium 92.91	42 Mo 1.8 molybdenum 95.94	43 Tc 1.9 technetium 98.91	44 Ru 2.2 ruthenium 101.07	45 Rh 2.2 rhodium 102.91	46 Pd 2.2 palladium 106.40	47 Ag 1.9 silver 107.87	48 Cd 1.7 cadmium 112.41	49 In 1.7 indium 114.82	50 Sn 1.8 tin 118.69	51 Sb 1.9 antimony 121.75	52 Te 2.1 tellurium 127.60	53 I 2.5 iodine 126.90	54 Xe - xenon 131.30
55 Cs 0.7 cesium 132.91	56 Ba 0.9 barium 137.33	57-71	72 Hf 1.3 hafnium 178.49	73 Ta 1.5 tantalum 180.95	74 W 1.7 tungsten 183.85	75 Re 1.9 rhenium 186.21	76 Os 2.2 osmium 190.20	77 Ir 2.2 iridium 192.22	78 Pt 2.2 platinum 195.09	79 Au 2.4 gold 196.97	80 Hg 1.9 mercury 200.59	81 Tl 1.8 thallium 204.37	82 Pb 1.8 lead 207.19	83 Bi 1.9 bismuth 208.98	84 Po 2.0 polonium (209)	85 At 2.2 astatine (210)	86 Rn - radon (222)
87 Fr 0.7 francium (223)	88 Ra 0.9 radium 226.03	89-103	104 Rf - rutherfordium (206)	105 Ha - hahnium (260)	106 - (263)	107 -											

57 La 1.1 lanthanum 138.91	58 Ce 1.1 cerium 140.12	59 Pr 1.1 praseodymium 140.91	60 Nd 1.2 neodymium 144.24	61 Pm - promethium (145)	62 Sm 1.2 samarium 150.35	63 Eu - europium 151.96	64 Gd 1.1 gadolinium 157.25	65 Tb 1.2 terbium 158.93	66 Dy - dysprosium 162.50	67 Ho 1.2 holmium 164.93	68 Er 1.2 erbium 167.26	69 Tm 1.2 thulium 168.93	70 Yb 1.1 ytterbium 173.04	71 Lu 1.2 lutetium 174.97
89 Ac 1.1 actinium (227)	90 Th 1.3 thorium 232.04	91 Pa 1.5 protactinium 231.04	92 U 1.7 uranium 238.03	93 Np 1.3 neptunium 237.05	94 Pu 1.3 plutonium (244)	95 Am 1.3 americium (243)	96 Cm - curium (247)	97 Bk - berkelium (247)	98 Cf - californium (251)	99 Es - einsteinium (254)	100 Fm - fermium (257)	101 Md - mendelevium (258)	102 No - nobelium (259)	103 Lr - lawrencium (260)

Physics 30

Student Module Booklet

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